Center for Environmentally Sustainable Transportation in Cold Climates

Examination of the Variability in Grout Test Results

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Keyway grouting is an operation that connects decked bulb-tee girders into one system. The quality of grout should be well maintained through reliable material test procedures. Due to the issues of discrepancy and variability, there have been several cases in which grout materials did not satisfy the compressive strength standard specified in the DOT&PF Standard Specifications for Highway Construction. This research examined the causes of such issues. Six factors – grout material, mix consistency, workmanship, initial curing/storing, curing method, and test equipment – were identified as the causes of strength variation. Their effects on strength variation were investigated by testing compressive strength of cube and cylinder specimens made from 5 grout materials that were used or considered to be used in DOT&PF projects. Grout material characteristics such as grout material and mix consistency have significant effect on strength variation. Workability and consolidation can be different from one material to another. Consequently, they affect compressive strength and its variation. Workmanship and test equipment were evaluated in this research to have moderate effect on strength variation. Especially, strength variation can increase when the workmanship factor combines with the grout material characteristics factor.

14- KEYWORDS : Longitudinal Keyway Joint, High-Strength Grout, Compressive Strength, Variability

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Table of Contents

List of Figures

List of Tables

EXECUTIVE SUMMARY

Keyway grouting is an operation that connects decked bulb-tee girders into one system. The quality of grout should be well maintained through reliable material test procedures. Due to the issues of discrepancy and variability, there have been several cases in which grout materials did not satisfy the compressive strength standard in the *Alaska Department of Transportation and Public Facilities (DOT&PF) Standard Specifications for Highway Construction*. This research examined the causes of such issues.

The research identified six factors – grout material, mix consistency, workmanship, initial curing/storing, curing method, and test equipment – as the causes of strength variation. Their effects on strength variation were investigated by testing compressive strength of cube and cylinder specimens made from five grout materials that were used or considered for use in DOT&PF projects.

Grout material characteristics such as grout material and mix consistency have significant effect on strength variation. Workability and consolidation can be different from one material to another. Consequently, they affect compressive strength and its variation. This research evaluated workmanship and test equipment to have moderate effect on strength variation. Especially, strength variation can increase when the workmanship factor combines with the grout material characteristics factor. The test equipment factor can generate inconsistent test results compared to the previous results of the same grout material. Initial curing/storing of cube specimens and curing method have only a minor effect on strength variation.

This research recommends reinforcing training activities in order to reduce effects on strength variation due to grout material characteristics and workmanship. Enhancing the

understanding of grout materials needs to be implemented in training activities. Regular hands-on training to improve cube-making workmanship is advised. Technicians need regular skill training for initial curing/storing, transporting and testing cube specimens.

The following are findings of this research:

- The survey results indicate that the DOT&PF standard specification of 9,000 psi for minimum 28-day strength of keyway grout is higher than that of other state DOTs. From other states, there is limited information and lack of experience about strength variation in test results for the high-strength grout materials used in bridge keyway joints.
- Grout material characteristics such as grout material and mix consistency have significant effect on strength variation. Workability and consolidation can be different from one material to another. Consequently, they affect compressive strength and its variation. Even a well-trained technician could have difficulty and induce strength variation due to grout material characteristics.
- Workmanship and test equipment were evaluated to have moderate effect on strength variation. Especially, strength variation can increase when the workmanship factor combines with the grout material characteristics factor. The test equipment factor can generate inconsistent test results compared to the previous results of the same grout material.
- Initial curing/storing of cube specimens and curing method have only a minor effect on strength variation.

- Measurements of the elastic moduli of four grout materials showed variation across different materials. They varied from 3,285 ksi – 4,457 ksi at 7-day, and the range was 3,752 ksi – 4,557 ksi at 28-day.
- The compressive strengths of cube and $\phi 4'' \times 8''$ cylinder specimens were compared. The cylinder strength was 77% – 86% of cube strength.
- For Sure-Grip®, the probability of having a variation greater than 8.7% among three cubes was 0.122 based on a lognormal probability distribution.
- The mean and the standard deviation for Sure-Grip® and Sakrete® were estimated. For both materials, the coefficient of variation was 2.7%. Statistical evaluation based on a coefficient of variation of 2.7% showed that the variability limit of three cubes can be 11.12% (from 8.7%), and the variability limit of two cubes can be 9.84% (from 7.6%).
- This research showed that ATM 507 procedures were appropriate and more applicable than ASTM C1107 (combined with ASTM C109) in molding cube specimens from grout materials. Two modifications to ATM 507 were proposed. The research recommended hand tamping as a primary consolidation method over puddling for flowable mix consistency.
- The compressive strength of PPC was less than non-shrink, cementitious grout materials tested in the present research. The mean and the standard deviation of strengths were calculated, and strength variability limits for PPC were provided.
- The elastic modulus of PPC was less than half of elastic modulus of non-shrink, cementitious grout materials used in the present research. The strain at the peak stress

was much larger than cementitious grouts. PPC substantially deformed before and after the peak stress.

CHAPTER 1. INTRODUCTION AND RESEARCH APPROACH

1.1 Problem Statement and Research Objective

Alaska's brief summers make bridge construction more challenging. Because of the short construction season, precast, pre-stressed decked bulb-tee (DBT) girders have been widely adopted to accelerate bridge construction across Alaska by the Alaska Department of Transportation and Public Facilities (DOT&PF). Using DBT girders eliminates the need to cast and cure a conventional cast-in-place concrete deck, consequently accelerates the superstructure construction time (Daugherty and Marx 2014, DOT&PF 2016). In Alaska, 80% of recently constructed bridges are of this type (spans are up to 145 feet). After the installation of DBT girders at the construction site, a bridge deck is constructed by connecting the wide top flanges of DBT girders with grout. High-strength, non-shrink grout is typically used in constructing longitudinal keyway joints.

As specified in the *Standard Specifications for Highway Construction* (DOT&PF 2017), the grout should be "non-shrink, non-corrosive, non-metallic, cement-based grout meeting ASTM C1107 (ASTM 2014b), except developing a 28-day compressive strength of at least 9,000 psi when tested according to AASHTO T106 or ASTM C109." The variability limits in ASTM C109 (ASTM 2016) are stated that the maximum permissible range of compressive strength is 8.7% of the average when three cubes represent a test age and 7.6% when two cubes represent a test age.

According to previous experiences, however, test results (28-day compressive strength) in some cases, especially when tested using cube specimens, did not satisfy the requirements in the DOT&PF Specifications. In most cases, none of the compressive strength tests satisfied the variability limits in ASTM C109 when the strength exceeded 9,000 psi, or the compressive strength was less than 9,000 psi if the test results satisfied the variability limits in ASTM C109. The research objectives in this study are:

i. To provide a third-party verification of the variation and discrepancy in the compressive strength test results of grout materials used in current bridge construction.
ii. To identify the causes of the variation and discrepancy in the grout test results.
iii. To propose solutions that will provide a more constructible and contractually administrable procedure to satisfy the quality needs of grouted bridge keyways.

1.2 Scope of Study

Table 1-1 shows some non-shrink, non-corrosive, non-metallic, cementitious grout products used or approved for use in past bridge projects in Alaska. The manufacturer specified 28-day strength is strong enough for most products in plastic (dry-pack) consistency. Dayton Superior Sure-Grip® High Performance Grout satisfies the strength requirement in all consistencies. This research studied the five materials listed in Table 1-1.

Table 1-1. Manufacturer specified 28-day compressive strength of grout materials used in Alaska projects (psi)

Product	Consistency			Project (Used or Considered)
	Plastic (Dry-Pack)	Flowable	Fluid	
Sakrete® Precision Non-shrink Grout[1] (Sakrete®)	12,500	10,500	8,000	Tulsona Creek
Dayton Superior 1107 Advantage Grout (Advantage)	10,000	8,000	7,500	Glenn/Muldoon Interchange
MAPEI Planigrout 712 (Planigrout)	9,000	8,000	6,500	Glenn/Muldoon Interchange
Dayton Superior Sure-Grip® High Performance Grout (Sure-Grip®)	12,500	10,000	9,000	Chicken Creek and Slana River
BASF Masterflow® 928 High Strength Grout (Masterflow®)	9,000	8,000	7,500	

1.3 Research Approach

1.3.1 Research Tasks

The following four tasks were set for this research:

- Task 1: Literature Review and Field Survey/Site Visits
- Task 2: Development of Laboratory Testing Plan
- Task 3: Laboratory Testing and Data Analysis
- Task 4: Draft of Report and Dissemination

In Task 1, the research conducted a comprehensive literature search of published materials and on-going research projects on relevant practice and construction techniques for grouting in bridge superstructure construction. Survey questions were distributed to bridge

[1] The manufacturer changed the strength data recently. The product name also changed. Previously, the product name was Non-shrink Construction Grout.

engineers at state DOTs and other related agencies. The research team visited bridge construction sites to collect grout cube samples for the compressive strength test.

In Task 2, the research developed a laboratory-testing plan to investigate variability and discrepancy. The DOT&PF technical advisory committee (TAC) reviewed and finalized the plan.

In Task 3, the University of Alaska Fairbanks (UAF) research team worked with the DOT&PF Northern Region (DOT&PF–NR) Materials Laboratory to accomplish physical specimen preparation and testing. Researchers statistically analyzed and evaluated the results to identify the potential factors that cause variation and discrepancy in results.

Task 4 involved quarterly reports, an interim report, a final report, and dissemination of information.

1.3.2 Laboratory Testing

For Task 2, a laboratory-testing plan for grout compressive strength was drawn. While conducting Task 1, the potential causes of variation and discrepancy in compressive strength test results were identified (see summary in Table 1-2). Task 3 assessed the effect of those factors.

In order to streamline laboratory testing, strength tests were performed in the following five rounds. Rounds 1 and 2 focused on assessing a single cause. Round 3 focused on multiple causes. Round 4 included specimen molding and initial curing/storing. Round 5 investigated new types of grout material that can serve better to reduce variability and discrepancy.

- Round 1: workmanship
- Round 2: curing method (water bath vs. moisture cabinet)

- Round 3: grout product + consistency, cube vs. cylinder, test equipment
- Round 4: initial curing/storing
- Round 5: new types of grout material

Table 1-2. Potential causes of variations in compressive strength

Classification	Potential Causes
Primary Causes	• Grout product (extended with pea gravel or not, working time) • Consistency (water content and quality, mixing, working time)
Secondary Causes	• Workmanship during specimen molding (mold condition, temperature), handling, and transporting • Initial curing/storing
Minor Causes	• Curing methods (moisture cabinet, water bath, etc.) and temperature during curing • Test equipment

Round 1

Testing in round 1 used Sure-Grip® to make cube specimens in two different consistencies: flowable and fluid. Recently, several bridge projects in DOT&PF–NR used Sure-Grip®. The manufacturer specified 28-day strengths of flowable mix consistency and fluid mix consistency are 10,000 psi and 9,000 psi, respectively. In Round 1, UAF researchers invited five technicians from the DOT&PF–NR office to the UAF laboratory. In the first two of a total three visits, DOT&PF–NR technicians made cube specimens as they normally did in the field. In the third visit, the UAF researchers trained the technicians before specimen molding to improve the quality of specimens. Table 1-3 shows the number of specimens and strength test age per technician. The UAF research team made the grout mixture. Specimens were cured in a moisture cabinet then tested at UAF.

Table 1-3. Specimens for Round 1 (per technician)

Grout Material	Strength Test	Number of Specimens	Remark
Sure-Grip® (flowable)	7-day and 28-day	6 cubes	1st visit
Sure-Grip® (fluid)	7-day and 28-day	6 cubes	2nd visit
Sure-Grip® (fluid)	7-day and 28-day	6 cubes	3rd visit

Round 2

Round 2 examined curing condition as a potential cause of strength variation. A moisture cabinet (73°F and 95–99% RH) in Figure 1-1 and a conventional water bath were available at the UAF laboratory. The UAF team molded cube specimens from Sure-Grip® (flowable and fluid consistencies). Specimens were cured in different conditions. Table 1-4 shows the number of specimens and strength test ages per curing condition. Specimens were tested at the UAF laboratory.

Figure 1-1. Moisture cabinet at the UAF laboratory

Round 3

Round 3 evaluated strength variation due to several factors, mainly, grout materials, specimen types, and strength test equipment. The list that follows is of the five grout materials tested. The consistency condition to satisfy the 9,000 psi strength requirement is noted.

- Dayton Superior Sure-Grip® High Performance Grout (fluid consistency)
- Sakrete® Precision Non-shrink Grout (flowable consistency)
- Dayton Superior 1107 Advantage Grout (dry-pack consistency)
- MAPEI Planigrout 712 (plastic consistency)
- BASF Masterflow® 928 High Strength Grout (plastic consistency)

Table 1-4. Specimens for Round 2 (per curing condition)

Grout Material	Strength Test	Number of Specimens
Sure-Grip® (flowable)	1-day, 3-day, 7-day, 28-day	12 cubes
Sure-Grip® (fluid)	1-day, 3-day, 7-day, 28-day	12 cubes

Table 1-5 shows types of specimens and the number of specimens per grout material. The UAF team made the specimens. Grouts were mixed in an IMER Mortarman 120+ mortar mixer as shown in Figure 1-2. 12 – 2"×2" cubes and 12 – ϕ4"×8" cylinder specimens were transported to the DOT&PF–NR office after 24 hours. They were cured and tested at the DOT&PF–NR office. The rest were cured and tested at the UAF laboratory. One ϕ6"×12" cylinder was molded and tested for the evaluation of elastic modulus at the UAF laboratory.

Figure 1-2. IMER Mortarman 120+ mortar mixer

DOT&PF–NR technicians made additional batches from Sure-Grip® and Sakrete®. From each batch, 24 – 2"×2" cubes and 24 – ϕ4"×8" cylinders were molded. Half of the specimens were tested at the UAF laboratory; the other half were transported to the DOT&PF–NR office for curing and testing.

Table 1-5. Specimens for Round 3 (per grout material)

Specimen Type	**Strength Test**	**Number of Specimens**	**Test Location**
cube	1-day, 3-day, 7-day, 28-day	24 cubes	DOT&PF-NR, UAF
ϕ4"×8" cylinder	1-day, 3-day, 7-day, 28-day	24 cylinders	DOT&PF-NR, UAF
ϕ6"×12" cylinder	7-day, 28-day (elastic modulus)	1 cylinder	UAF

Round 4

Round 4 investigated the effects on strength variation due to initial curing/storing of specimens. The effect on compressive strength due to elevated temperature and demolding time was specifically studied. The UAF team made cube specimens from Sure-Grip® in fluid consistency and Sakrete® in flowable consistency. Table 1-6 shows different test cases.

Table 1-6. Test cases in Round 4 (for elevated temperature)

<table>
<tr><th>Grout Material</th><th>Strength Test</th><th>Number of Specimens</th><th>Remark</th></tr>
<tr><td rowspan="4">Sure-Grip® (fluid)</td><td rowspan="4">3-day, 7-day, 28-day</td><td>3: demolded at 24h (28-day)
9: demolded at 48h</td><td rowspan="3">Mixing water and molds were stored at 95°F; specimens in molds were stored in a cooler (61°F)</td></tr>
<tr><td>3: demolded at 24h (28-day)
9: demolded at 48h</td></tr>
<tr><td>3: demolded at 24h (28-day)
9: demolded at 48h</td></tr>
<tr><td>12: demolded at 24h
12: demolded at 48h</td><td>Mixing water and molds were stored at 81°F; specimens in molds were stored at 81°F before demolding</td></tr>
<tr><td>Sakrete® (flowable)</td><td>3-day, 7-day, 28-day</td><td>12: demolded at 24h
12: demolded at 48h</td><td>Mixing water and molds were stored at 81°F; specimens in molds were stored at 81°F before demolding</td></tr>
</table>

In addition, specimens from batches made by paddle mixing (Figure 1-3) were tested to evaluate the effects from different mixing methods. The test used Sure-Grip® in fluid consistency and Sakrete® in flowable consistency. Table 1-7 shows the number of specimens and strength test ages. From each batch, 24 cube specimens were made. Half of them were stored in a moisture cabinet and the other half were stored in a water bath. In mixing method B, all grout material was poured in a bucket before water was added. Unresolved grout remained stuck to bottom corner of the bucket after mixing. The following is the procedure for mixing method A, which is recommended. Mixing time and amount of water should be adjusted, following manufacturer's recommended procedure and mixing time.

Procedure for mixing method A:

1. Pouring 80-90% water in a bucket
2. Pouring all grout material in the bucket
3. Mixing for 2 minutes with a paddle mixer
4. Scraping unresolved grout from the bucket and paddle
5. Mixing for 2 minutes
6. Pouring the remaining water in the bucket
7. Mixing for 1 minute

Figure 1-3. Paddle mixing of grout

Table 1-7. Test cases in Round 4 (for paddle mixing)

Grout Material	Strength Test	Number of Specimens	Remark
Sure-Grip® (fluid)	1-day, 3-day, 7-day, 28-day	12: cabinet 12: bath	Mixing method B
Sure-Grip® (fluid)	1-day, 3-day, 7-day, 28-day	12: cabinet 12: bath	Mixing method A
Sakrete® (flowable)	1-day, 3-day, 7-day, 28-day	12: cabinet 12: bath	Mixing method A

Round 5

Round 5 tested Polyester Polymer Concrete (PPC), PPC 1121 by Kwik Bond Polymers. This material has been used in bridge deck overlay, grade correction, bridge joint, and patching application. The manufacturer specified compressive strength is 7,000 psi and a tensile strength is 800 psi (KwikBond Polymers 2018). The installation of PPC 1121 needs an application of KBP 204 primer on bonding surface. KBP204 primer is mixed with 6% Cobalt Drier and Cumyl Hydro Peroxide (KwikBond Polymers 2017). The PPC-1121 MM mix consists of PPC Binder Resin, DDM 9 (MEKP), Z Cure Accelerator, A-3038 rock, and B-11 sand.

Compressive strength of cube and ϕ4"×8" cylinder specimens made from PPC was tested. Two PPC batches were made to repeat test in order to collect more data, for PPC is relatively new material for grout. Table 1-8 shows the type and number of specimens. Bond strength was also tested from slant shear test.

Table 1-8. PPC test in Round 5

Batch	Test type	Specimens (number)	Test days
PPC-0604A	Compressive strength	Cubes (9)	3, 7, 28 days
		Cylinders (9)	3, 7, 28 days
	Slant shear strength	Cylinders (6)	7 and 28 days
		Cylinders (3)	28 days at -40°F

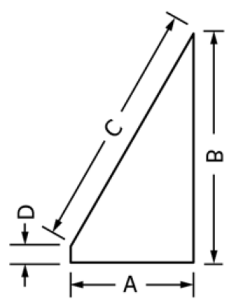
Batch	Test type	Specimens (number)	Test days
PPC-0604B	Compressive strength	Cubes (9)	3, 7, 28 days
		Cylinders (9)	3, 7, 28 days
	Slant shear strength	Cylinders (6)	7 and 28 days
		Cylinders (3)	28 days at -40°F

Slant shear test is a method that determines the bond strength between two materials. ASTM C882/C882M: *Standard Test Method for Bond Strength of Epoxy-Resin Systems Used With Concrete by Slant Shear* specifies the slant shear test that measures the bond strength of epoxy-resin-base bonding systems for use with Portland-cement concrete (ASTM 2013). Firstly, slanted half of a cylindrical concrete specimen is made with a dummy section as shown in Figure 1-4.

After the concrete is cured, the slanted concrete section is placed in the bottom of a mold. The top half space is filled with epoxy-resin-base bonding material. The bond strength is estimated through dividing the load carried by the specimen at failure by the area of the bond surface.

The size and cross section of a specimen for the slant shear test can vary. For example, BS EN 12615 uses a specimen having a 4″×4″ (100 mm×100 mm) square section with a height of 16″ (400 mm) and an interface angle of 30° from the vertical (BS 1999). For a modified slant shear test, Saldanha et al. (2013) used a 6″×6″ (150 mm×150 mm) square section specimen with a height of 24″ (600 mm) and an interface angle of 30°. Illinois DOT uses a ϕ4"×8" cylindrical specimen with an interface angle of 30° (IDOT 2012).

In Round 5, ϕ4"×8" cylindrical specimens with an interface angle of 30° were used for slant shear test of PPC. The slanted half of a specimen was made of the high-strength concrete used in DBT girder construction, and PPC was used for the other half. Additional specimens were stored at -40°F and tested for the 28-day strength.



	Dimensions	
	mm	in.
A—Diameter	75±2	[3.00 ± 0.08]
B—Height	140±2	[5.60 ± 0.08]
C—Slant height	150±2	[6.00 ± 0.08]
D—Base height	10±2	[0.40 ± 0.08]

Figure 1-4. Dummy section (ASTM 2013)

CHAPTER 2. FINDINGS

2.1 State-of-the-Art Summary

Various non-metallic, cement-based grout materials are available in the market. Swenty and Graybeal (2013) observed that the bond strength of conventional, pre-bagged, cementitious materials to precast concrete is approximately half the tensile strength of grout materials. Ozyildirim and Moruza (2015) studied ultra-high performance concrete (UHPC) with steel fiber and engineered cementitious composite (ECC) as grout materials. Both UHPC and ECC were self-consolidating materials and required no vibration. The 28-day strength of used ECC and UHPC was 8,255 psi and 23,345 psi, respectively. In a recent study on the performance of rapid-hardening, pre-packaged repair materials, such as rapid-set, cement-based, and resin-based mortars or concretes, Yang et al. (2016) showed that very high strength (VHS: developing a compressive strength of 10 ksi or higher within 28 days) grout materials can develop larger shrinkage cracking. In the past, magnesium ammonium phosphate (MAP) mortar was known for its good performance (Gulyas et al. 1995, Gulyas and Champa 1997, Issa 2002). Oesterle et al. (2009) used MAP materials in the NCHRP 12-69 study for the investigation of precast deck panel connections.

For a compressive strength test of grout in AASHTO T106 (AASHTO 2015) and ASTM C109 (ASTM 2016), 2"×2" cube specimens are used. Many studies, including Elwell and Fu (1995) and Graybeal and Davis (2008), indicated that 2"×2" cube specimens may not be a suitable substitute for the ϕ4"×8" cylinder specimen. According to Graybeal and Davis (2008), however, the use of cube specimens became increasingly popular for high-strength materials because cube specimens require less force to break and surface preparation for tests is easier. Gulyas et al. (1995) proposed to use a factor of 0.75–0.80 in order to convert 2"×2" cube strength to ϕ4"×8" cylinder strength. The variation of compressive strength test results has been reported in some studies (Porter 2009, De Murphy et al. 2010). For the non-shrink, cementitious grout materials used in Varga and Graybeal (2016), the strength could not reach the value specified by the manufacturer, or the variation of test results was significant although the 28-day strength was less than 9,000 psi.

The DOT&PF adopted the performance requirements in ASTM C1107 in its grout specifications, though increasing the 28-day strength requirement to 9,000 psi. It was expected that the minimum strength of grout should be at least equal to the strength of the connecting concrete members. However, prior testing reports that the bond strength was less than cracking strength of adjoining materials. The interface between the existing concrete surface and the grout tends to crack first in many applications (Issa et al. 1995, Swenty and Graybeal 2013). Shrinkage cracking usually occurs in the connection region that eventually propagates during cyclic loading (Haber and Graybeal 2015). Surface preparation by pressure wash or sand blast did not prevent shrinkage cracking between the existing concrete and grout material (Scholz et al. 2007).

Matsumoto et al. (2001) studied a precast bent cap system and proposed performance criteria for grout used in the precast bent cap system. Table 2-1 shows selected properties from the proposed criteria. The compressive strength of grout was greater than the specified 28-day concrete compressive strength by a minimum of 1,000 psi. Calculations used a factor of 1.25 to convert cylinder strength to cube strength. A margin of 1,000 psi accounted for the likelihood that actual concrete strength exceeds specified strength, as well as the possibility of low grout strength.

Table 2-1. Performance criteria of precast bent cap grout (Matsumoto et al. 2001)

Property	Performance Criteria	Remark
Compressive strength	1 day: 2500 psi 3 days: 4000 psi 7 days: 5000 psi 28 days: max[5800 psi, $1.25\left(f'_{c,CAP}+1000\right)$]	ASTM C109
Flowability	Fluid consistency Efflux time: 20–30 seconds	ASTM C939
Set time	Initial: 3–5 hours Final: 5–8 hours	ASTM C191

The design compressive strength of Alaska DBT girders is usually in a range of 7,500–8,500 psi. The actual strength can be greater than the design value. For example, the measured 28-day strength by the UAF research team was 9,119 psi. Following the approach in Table 2-1, the specified compressive strength of cube grout specimens can be 1.25(8,500+1,000) = 11,875 psi. Additional information compiled through literature review is available in Appendix A.

The present research developed survey questions and distributed them to a number of professionals, mostly in the Bridge and Materials Sections of other state DOTs, in order to collect information regarding grout materials used in their projects. The responses show that the majority of agencies used cement-based grout as the standard grout for common application in bridge construction, and 60% of these grout mixes were reported to be non-shrink. State DOTs used construction specifications selected from their own set of standard construction specifications. Sixty percent of the DOT agencies used ASTM C1107 as the standard for producing grout materials in construction. Washington and Wyoming DOTs used their own standard specifications. No agency reported using any non-cementitious grout materials such as epoxy grouts[2]. This report includes survey questions and results in Appendix B.

When making specimens, most agencies (60%) used cube molds according to ASTM C109. Minimum specified compressive strength for grout cubes varies per application as reported by the Wyoming and Minnesota DOTs. The minimum compressive strength was 5,000 psi and 4,000 psi for Oregon and Washington DOTs, respectively. Figure 2-1 compares minimum compressive strengths for grout. In the *DOT&PF Standard Specifications for Highway Construction*, the minimum strength for keyway grout is 9,000 psi, which is higher than that specified by other state DOTs. Note that New York State DOT specifies 6,000 psi for the 7-day strength (NYSDOT 2018). The 28-day strength of the same grout may reach 9,000 psi.

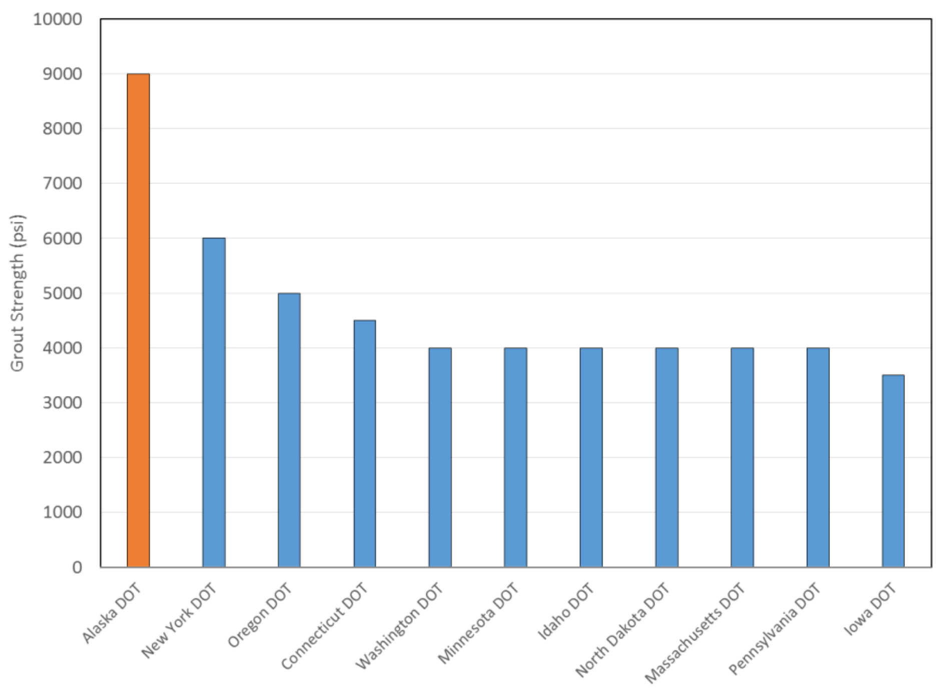


Figure 2-1. Comparison of minimum grout compressive strength (NOTE: (1) 7-day strength for New York State DOT and Iowa DOT; (2) 5,000 psi minimum strength for R3 type in North Dakota DOT.)

[2] Some states including Florida use epoxy-based grouts, but those agencies did not respond to the survey.

2.2 Construction Field Trips

The UAF research team visited three bridge construction sites to observe grouting operation procedure and to collect grout samples. In the summer of 2017, the team visited the Chicken Creek project site (7/12/2017) and the Slana River project site (7/17/2017). The team also visited the construction site on the Sterling Highway between mileposts 58 and 79 (7/20/2018). The team found that Sure-Grip® grout was used at both Chicken Creek and Slana River sites, and Sakrete® grout mixed with 3/8″ pea gravel was used at the site on the Sterling Highway. The in-field grouting operation was noted, and samples were transported to UAF for curing and testing. Appendix G contains detailed descriptions of the field trips.

Figure 2-2 shows the compressive strength test results from the Chicken Creek project. UAF researchers and two DOT&PF technicians made specimens. The average strength was greater than the specified value by the manufacturer of grout, as depicted in the figure by a dotted black line. The strength variation exceeded the limit (8.7%) in 2 out of 11 sets of cubes. For all cube sets tested, the 28-day strength was greater than 9,000 psi.

Figure 2-3 shows the test results of cube specimens collected from the Slana River project. The average strength on test days was greater than the specified value by the manufacturer, as depicted in the figure by a dotted black line. Variation exceeded the limit of 8.7% in 1 out of 12 sets of cubes. For all sets tested, the 28-day strength was greater than 9,000 psi.

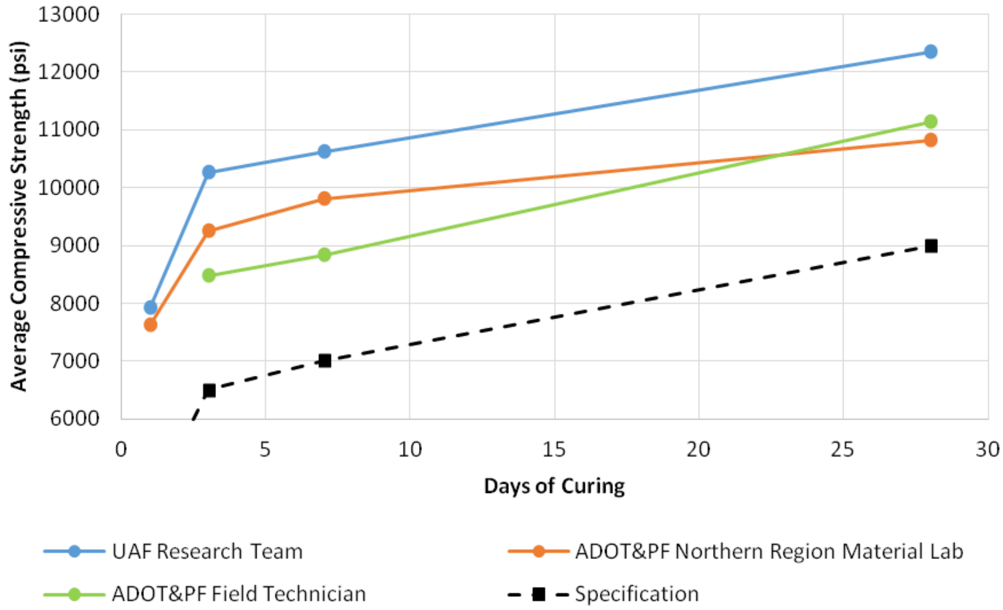


Figure 2-2. Average compressive strength of grout from Chicken Creek

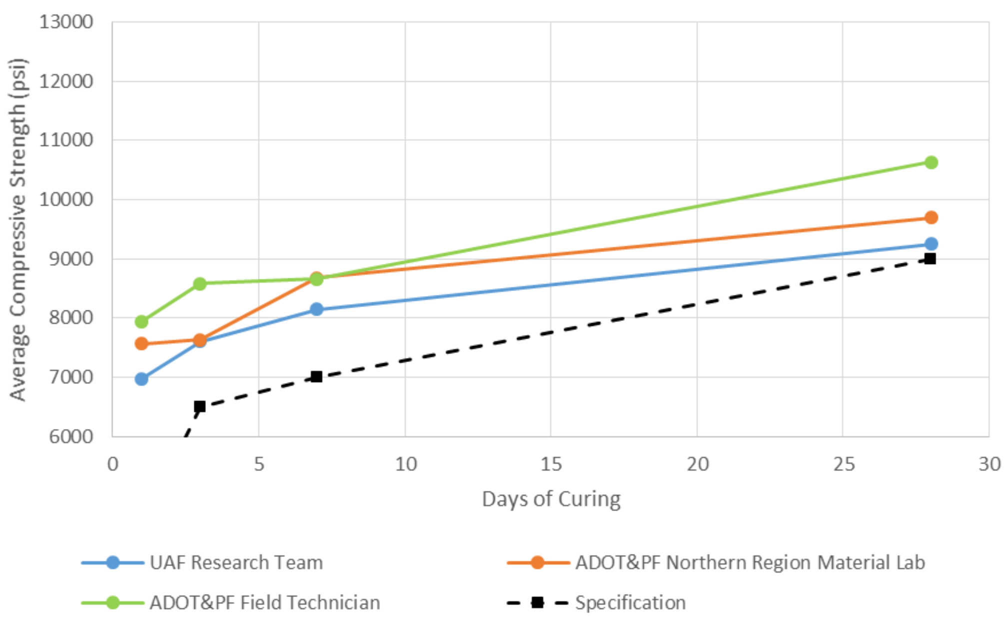


Figure 2-3. Average compressive strength of grout from Slana River

Figure 2-4 shows the compressive strength test results from the site on the Sterling Highway. The 28-day strength test used six cubes. The maximum variation among specimens on three test days (3-day, 7-day, 28-day) was less than the variability limit of 8.7%. The average 28-day strength was 9,947 psi, which is greater than 9,000 psi.

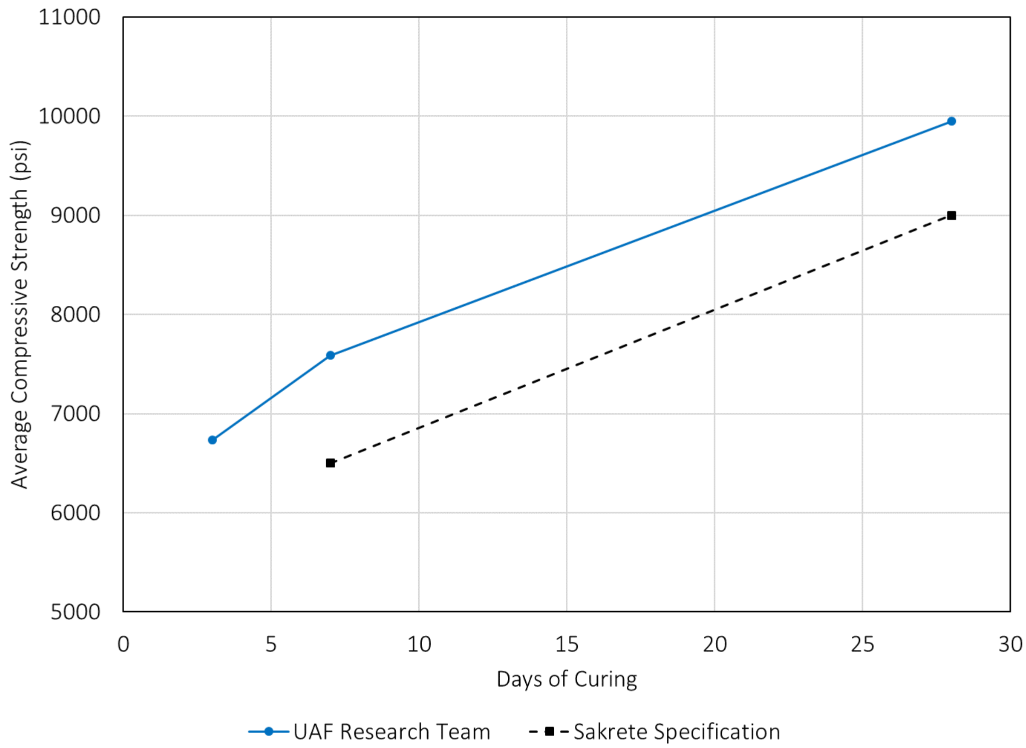


Figure 2-4. Average compressive strength of grout from the site on the Sterling Highway

The compressive strength test results on the specimens collected from the aforementioned three bridge construction sites did not reveal any issues related to excessive variation or lowered strength.

2.3 Round 1 Test Results

In Round 1, the five DOT&PF–NR technicians who were invited to the UAF laboratory made cube specimens from Sure-Grip® in two consistencies: fluid and flowable. Alongside, two UAF researchers made cube specimens with DOT&PF–NR technicians. Figures 2-5 and 2-6 show 7-day and 28-day strength test results, respectively. Each column in the figures indicates the average strength of three cubes, and two bars on a column show the maximum and minimum strength. When the variation of three cubes, $\left(\dfrac{Max - Min}{Average}\right)$, is greater than the limit of 8.7%, the color of a column was changed to orange. For all 13 sets of cubes, the average (and minimum) strength was greater than the strength specified by the manufacturer. There was only one case where the 8.7% variability limit was not satisfied.

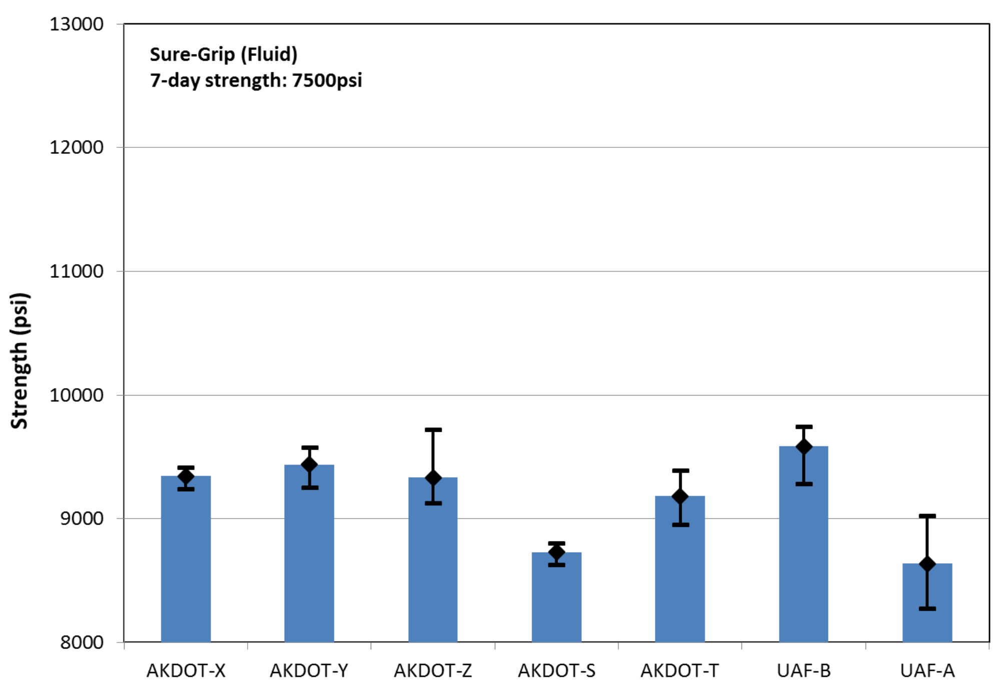


Figure 2-5. Strength test result (Round 1, fluid consistency, 7-day)

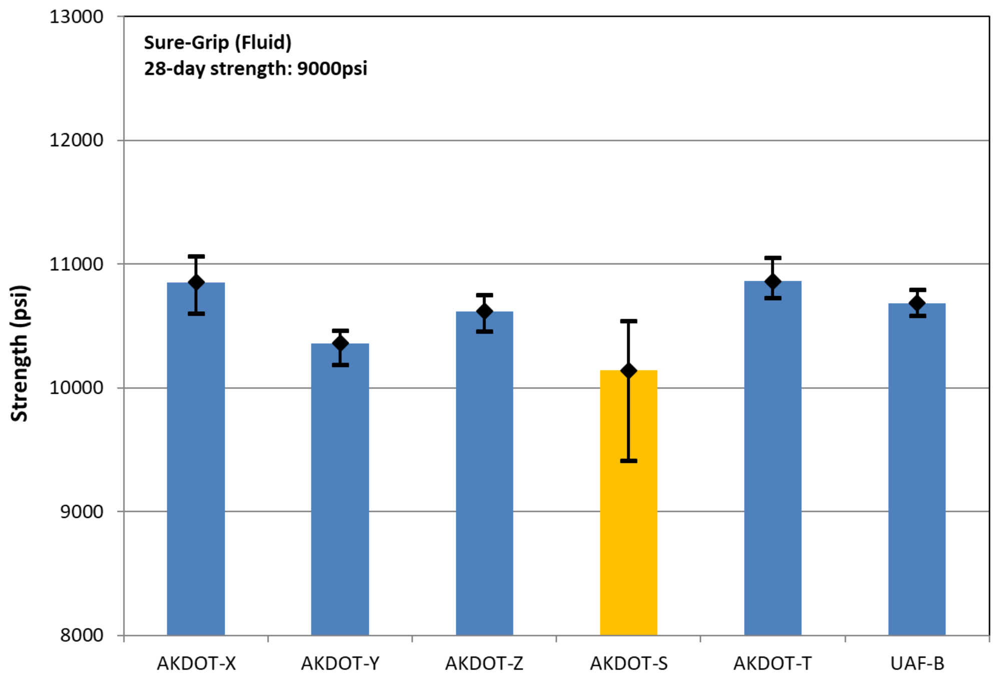


Figure 2-6. Strength test result (Round 1, fluid consistency, 28-day)

Figures 2-7 and 2-8, respectively, show 7-day and 28-day strength test results of flowable mix grout. For all sets of tested cubes, the minimum strength (lower bar in each column) was greater than the strength specified by the manufacturer (values at the top of each figure). There were two cases where the variation did not satisfy the limit (8.7%), as indicated by the orange columns.

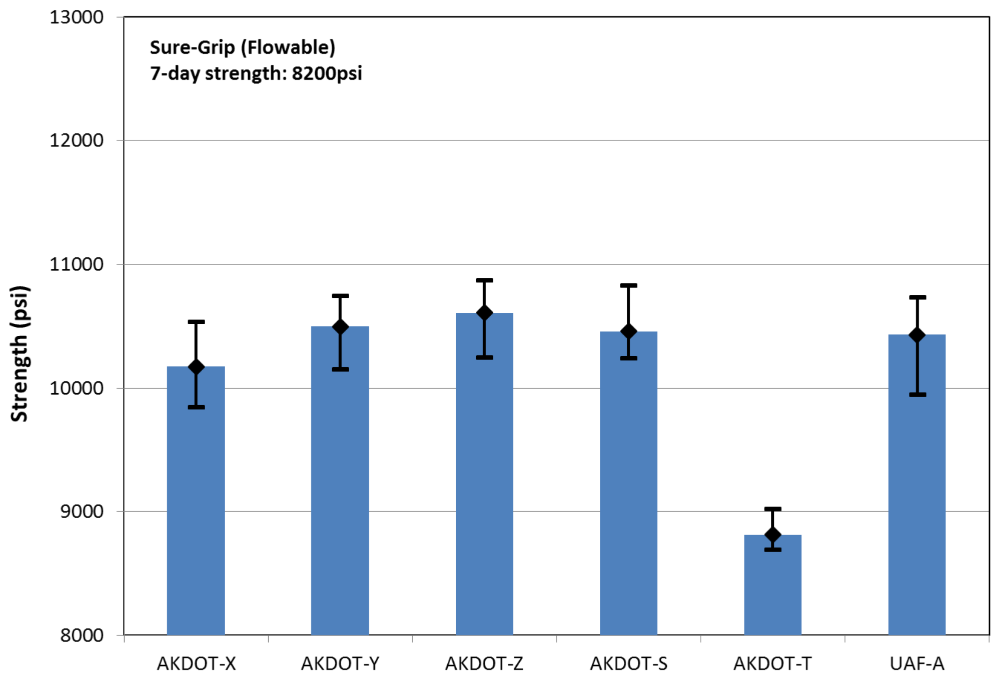


Figure 2-7. Strength test result (Round 1, flowable consistency, 7-day)

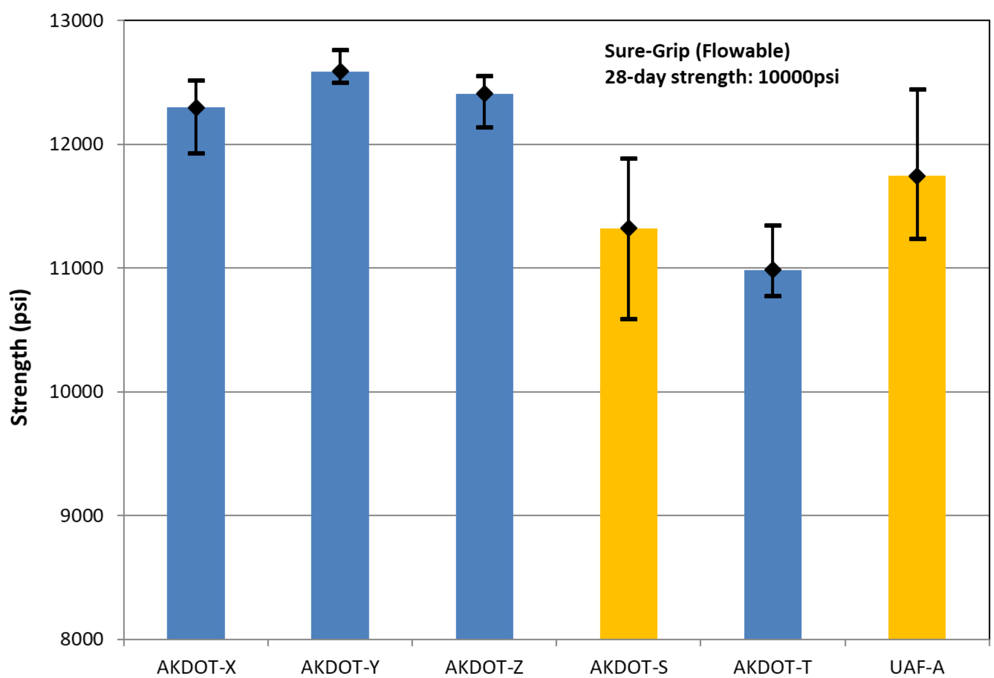


Figure 2-8. Strength test result (Round 1, flowable consistency, 28-day)

In Figure 2-7, the strength of one set is smaller than the other sets. The average of this set was 8,813 psi, whereas, the average of other sets is over 10,000 psi. A similar result is seen in Figure 2-8. The average strength of the smallest set is 10,983 psi, and the average strength of the first three sets is over 12,000 psi. The difference in workmanship could be the reason. Depending on skill sets in molding specimens, the average strength can vary by 1,000 psi or more. However, lower average strength did not necessarily imply greater variation. The variation of those sets having lower average strength was relatively small.

Figures 2-9 and 2-10 show strength test results after training. The training focused on making cube specimens with uniform quality between technicians. Good skills among technicians were passed around. The recommended skills are:

- Using pliers to tighten the wing nuts of a cube mold assembly to reduce gaps between pieces;
- Mixing grout mix well every time before filling a mold; and
- Practicing cutting action with a trowel to remove excessive grout mix on the top face of a cube.

A comparison of Figures 2-9 and 2-10 with Figures 2-5 and 2-6 shows that the average strength became more uniform as a result of training. However, the variation did not improve, which indicates the random nature of variation.

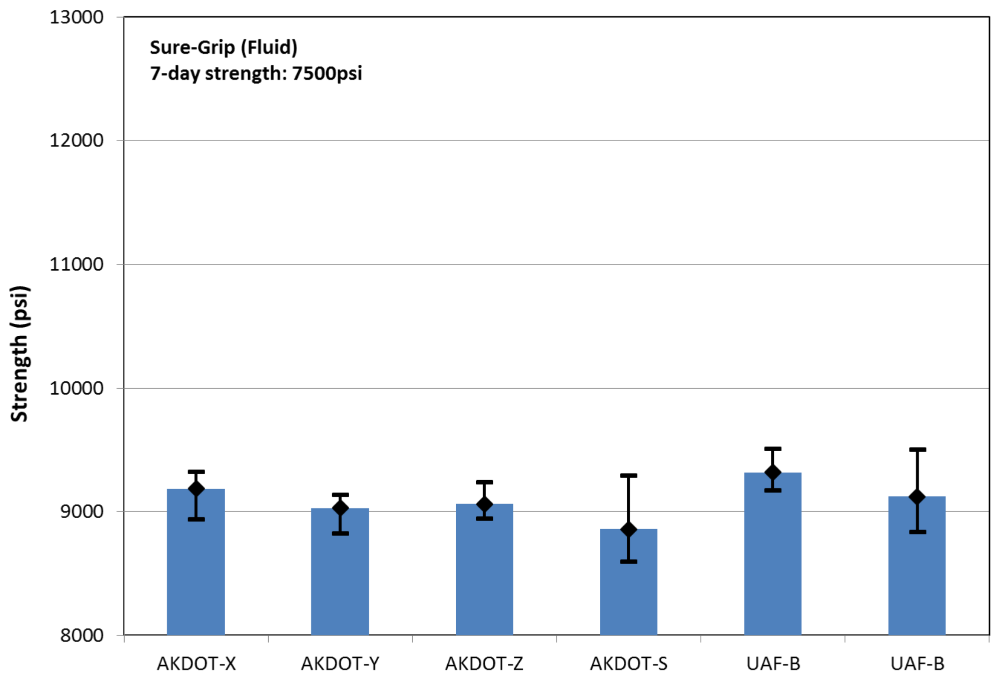


Figure 2-9. Strength test result (Round 1, fluid consistency, after training, 7-day)

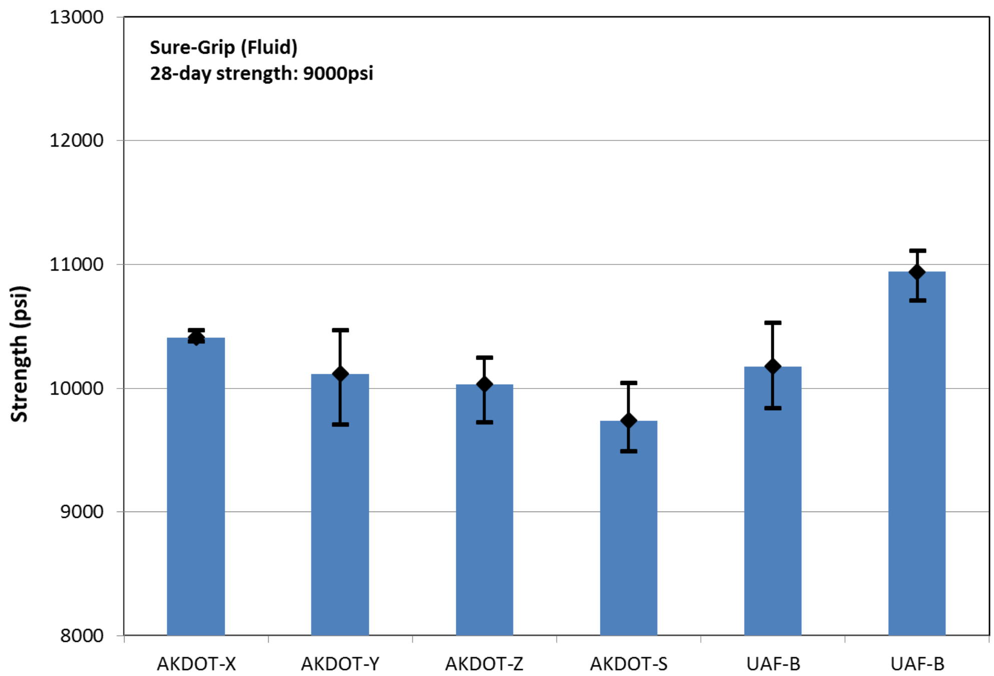


Figure 2-10. Strength test result (Round 1, fluid consistency, after training, 28-day)

During Round 1, differences in grout packaging bags and surface lubricant for a mold were proposed as possible sources of variation. A single UAF researcher made cube specimens from four different bags, and the 3-day and 7-day strengths of the specimens were compared, as shown in Figure 2-11. Two sets did not satisfy the variability limit of 8.7% (orange columns). The average strength values between different bags were consistent, which indicates negligible effect on the variation and discrepancy of strength test results.

When cube molds were assembled at the beginning of Round 1, petroleum jelly (Vaseline) was spread on the surface of a mold as lubricant. In Figures 2-5 and 2-6, the three sets from the left are the ones on which Vaseline was applied. Since a spray can (PAM) is typically used in DOT&PF–NR, PAM was sprayed in all other cases. To investigate the effect of different lubricant products, specimens were made by a single UAF researcher, and their 3-day and 7-day strengths were tested. Figure 2-12 shows that the average strength between two sets is close. In result, there is only a negligible effect on variation and discrepancy. Interestingly, the gap between the maximum and minimum strengths was smaller in specimens where Vaseline was applied than in specimens where PAM was sprayed.

In Round 1, 37 sets of three cubes were tested. Five DOT&PF–NR technicians and two UAF researchers made the cubes. The minimum strength of each set was greater than the specified strength either on 7-day or on 28-day. Overall, three sets did not satisfy the variability limit of 8.7%. Round 1 also indicated that workmanship can produce specimens with lower strength. It was shown that simple training could improve uniformity in average strength between technicians. However, the variation of strength did not correspondingly improve.

Additional test results indicate that the effects of different grout packaging bags and different surface lubricant products are negligible.

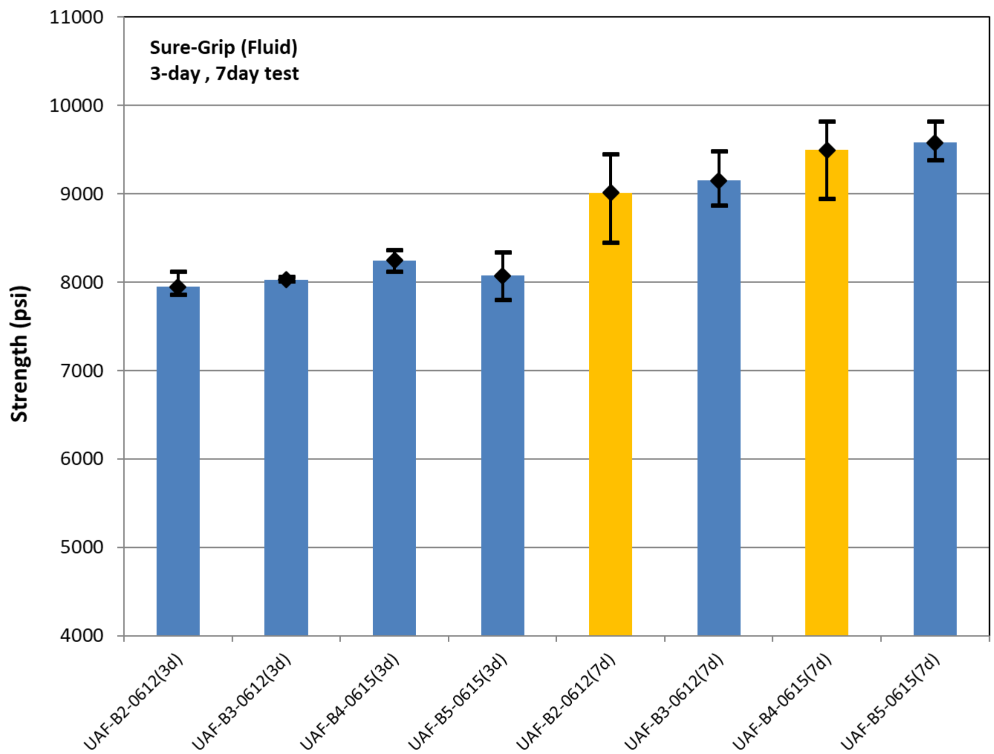


Figure 2-11. Strength test result (different bag, fluid consistency)

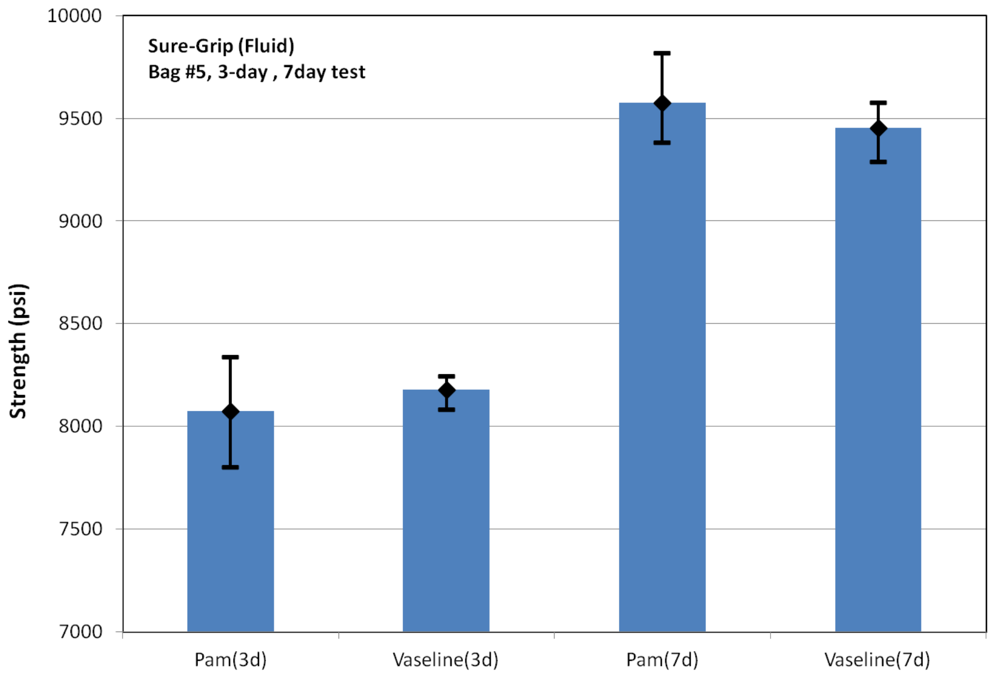


Figure 2-12. Strength test result (Pam vs. Vaseline, fluid consistency)

2.4 Round 2 Test Results

Round 2 assessed the discrepancy and variation in strength test results caused by the curing condition of specimens. Two UAF researchers made cube specimens: Researcher A and Researcher B. Specimens with two mix consistencies, fluid and flowable, were made from Sure-Grip® grout. Half of the specimens were cured in a moisture cabinet (73°F and 95–99% RH); the other half were cured in a water bath after demolding the cubes 24 hours after casting. Specimens were tested for 3-day, 7-day, and 28-day compressive strengths. The strength test results between the two curing conditions were compared.

Figures 2-13, 2-14, and 2-15 show the strength test results of specimens in fluid consistency. Columns in orange color indicate cases where the variation exceeded the limit of

8.7%. In Figure 2-13, the maximum difference is 758 psi for the 28-day strength from specimens made by Researcher A. In Figures 2-14 and 2-15, where Researcher B made specimens, the maximum difference is 410 psi for the 28-day strength in Figure 2-14, and 659 psi for the 28-day strength in Figure 2-15.

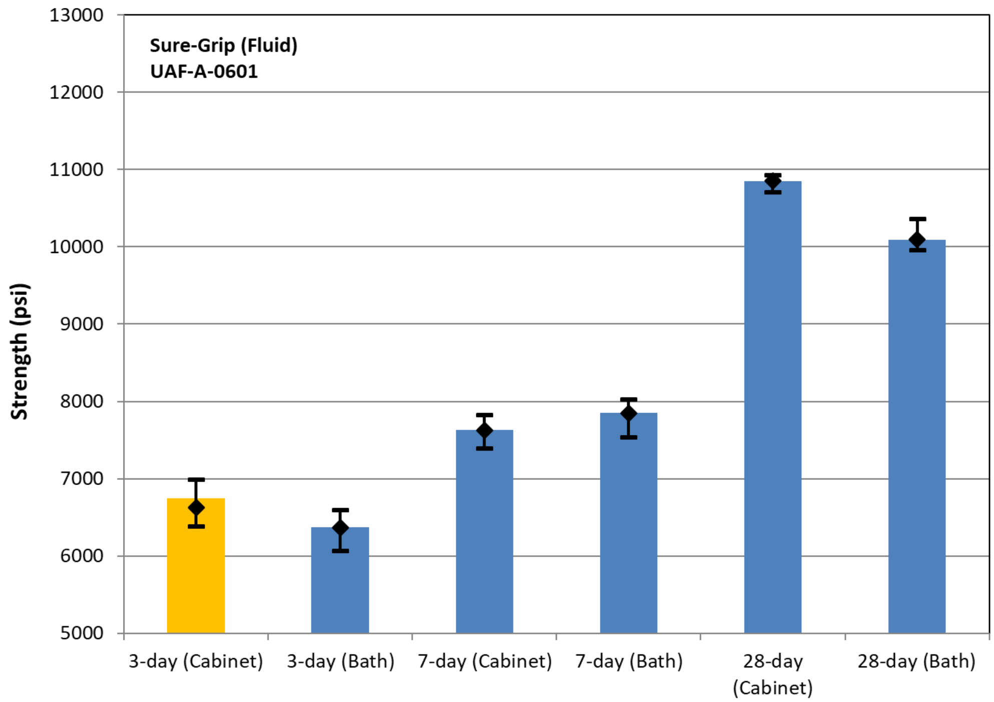


Figure 2-13. Strength test result (fluid consistency, UAF-A-0601 batch)

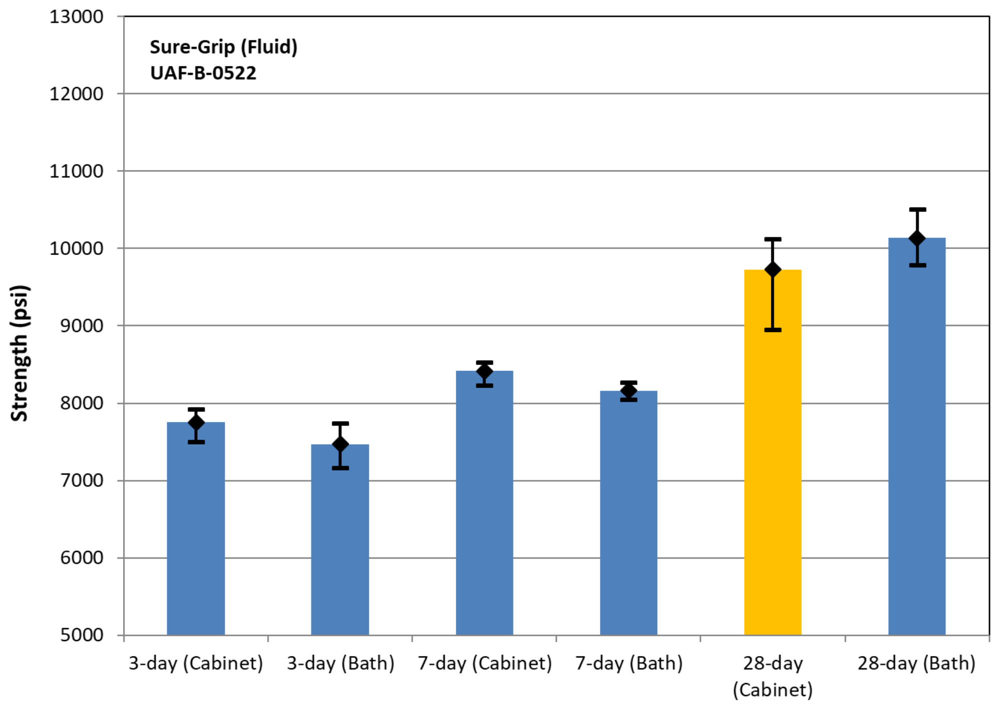


Figure 2-14. Strength test result (fluid consistency, UAF-B-0522 batch)

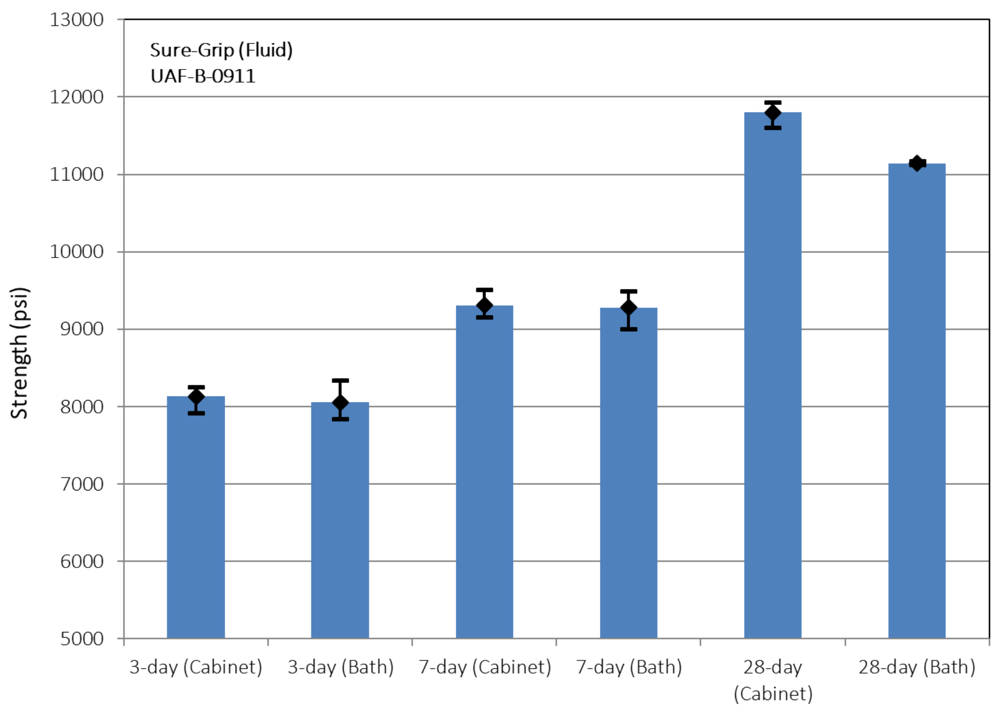


Figure 2-15. Strength test result (fluid consistency, UAF-B-0911 batch)

Strength test results of specimens in flowable mix consistency made by Researchers A and B are shown in Figures 2-16, 2-17, and 2-18. The maximum difference in strength occurred at the 28-day strength (1,163 psi) in Figure 2-16. For specimens made by Researcher B, the maximum difference was 720 psi in the 7-day strength in Figure 2-17, and the maximum difference was 1,230 psi in the 7-day strength in Figure 2-18.

To study difference between the two curing conditions, moisture cabinet and water bath, the analysis included more data from Rounds 1 and 3. Only the specimens made by Researcher B were used. The mean and standard deviation were calculated, and the analysis assumed that the strength at each test age is a random variable following a normal distribution.

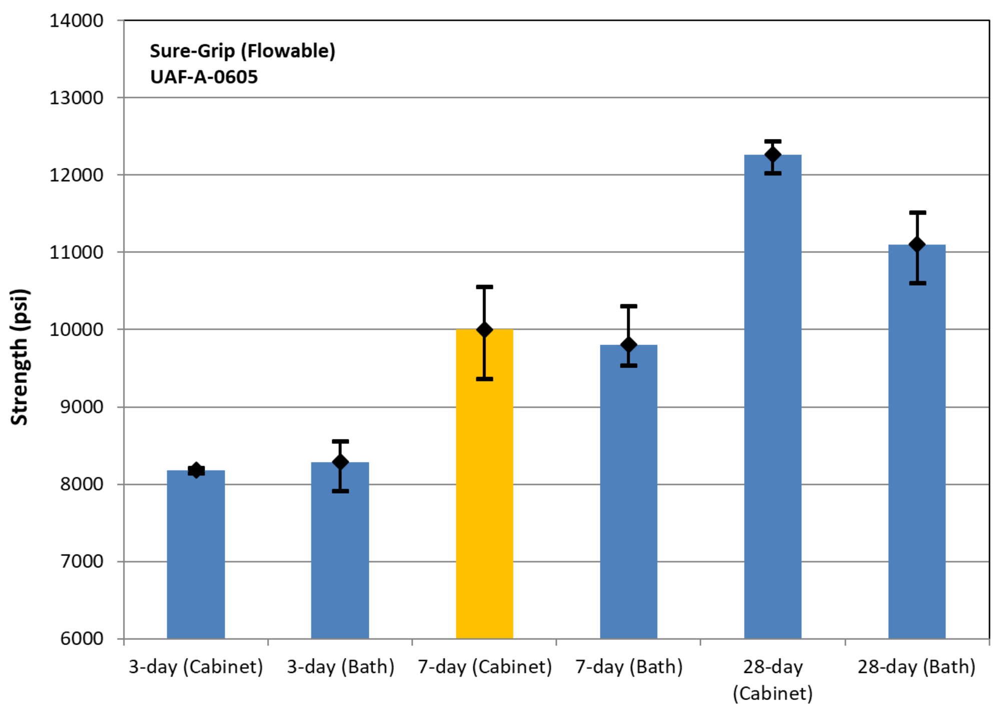


Figure 2-16. Strength test result (flowable consistency, UAF-A-0605 batch)

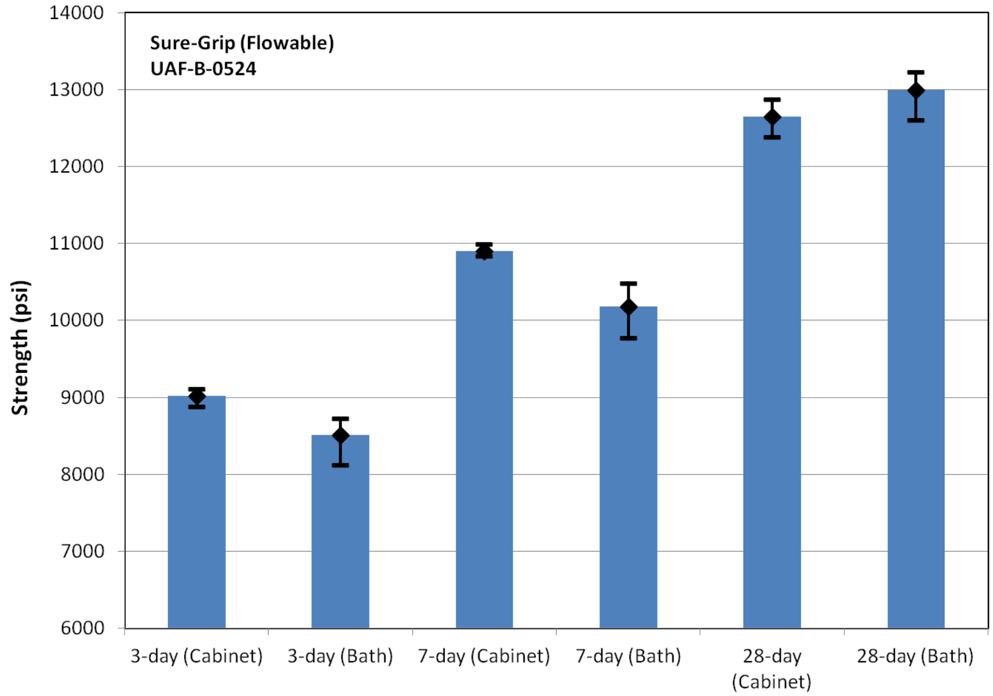


Figure 2-17. Strength test result (flowable consistency, UAF-B-0524 batch)

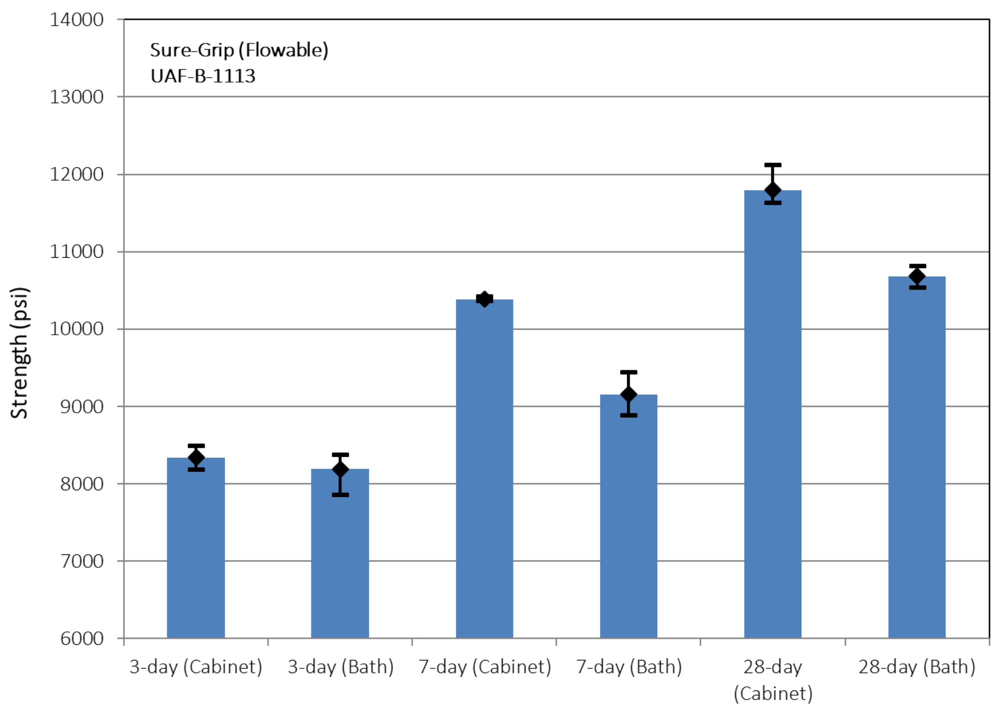


Figure 2-18. Strength test result (flowable consistency, UAF-B-1113 batch)

Figures 2-19, 2-20, and 2-21 are normal distribution models for the 3-day, 7-day, and 28-day strengths of specimens in fluid consistency. In all cases, the mean from cabinet curing was slightly greater than the mean from water bath curing, but the difference was minor. The difference was 306 psi for the 3-day strength, 254 psi for the 7-day strength, and 252 psi for the 28-day strength. From this comparison, the difference in strength between cabinet and water bath curing is minor or inconsequential for Sure-Grip® grout in fluid consistency.

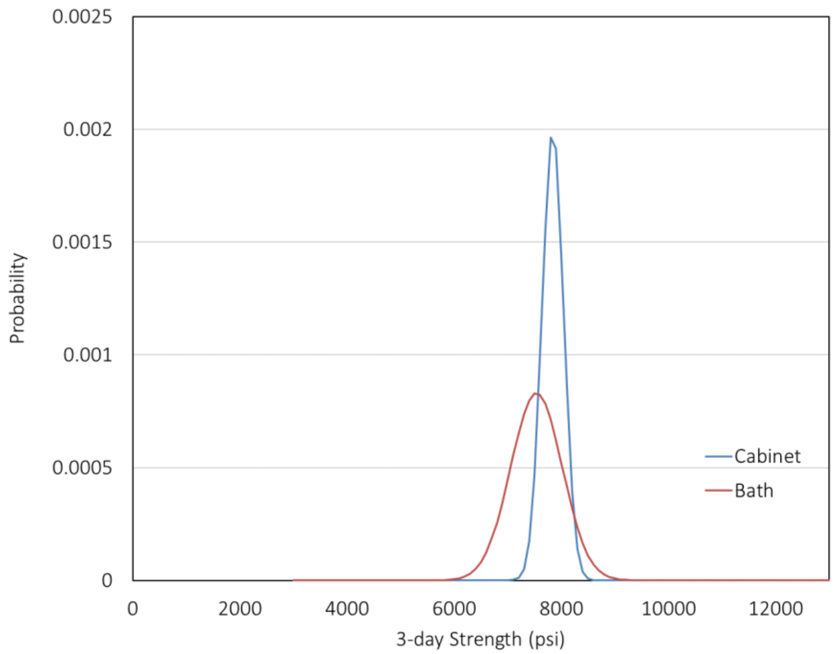


Figure 2-19. Normal distribution models for the 3-day strength (fluid consistency)

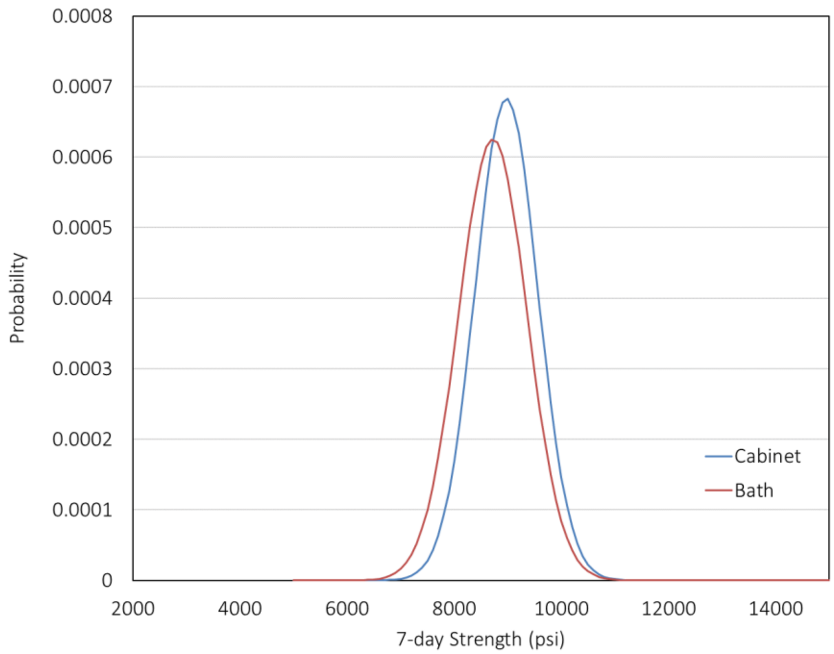


Figure 2-20. Normal distribution models for the 7-day strength (fluid consistency)

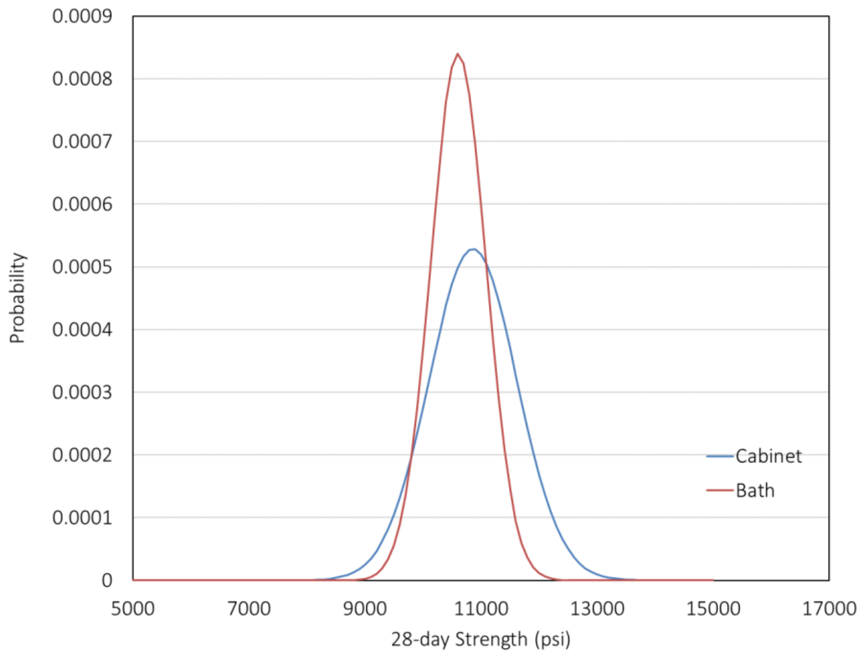


Figure 2-21. Normal distribution models for the 28-day strength (fluid consistency)

Normal distribution models for the 3-day, 7-day, and 28-day strengths of specimens in flowable consistency are compared in Figures 2-22, 2-23, and 2-24. The mean values from the two curing conditions were close, but the mean strength for cabinet curing was slightly greater for the 3-day and 7-day strengths. The difference in the mean values was 240 psi for the 3-day strength, 526 psi for the 7-day strength, and 58 psi for the 28-day strength. This comparison shows that the difference in strength between moisture cabinet and water bath curing is inconsequential for Sure-Grip® grout in flowable consistency.

In the following, data from moisture cabinet curing and water bath curing are combined when statistical analysis of data is needed.

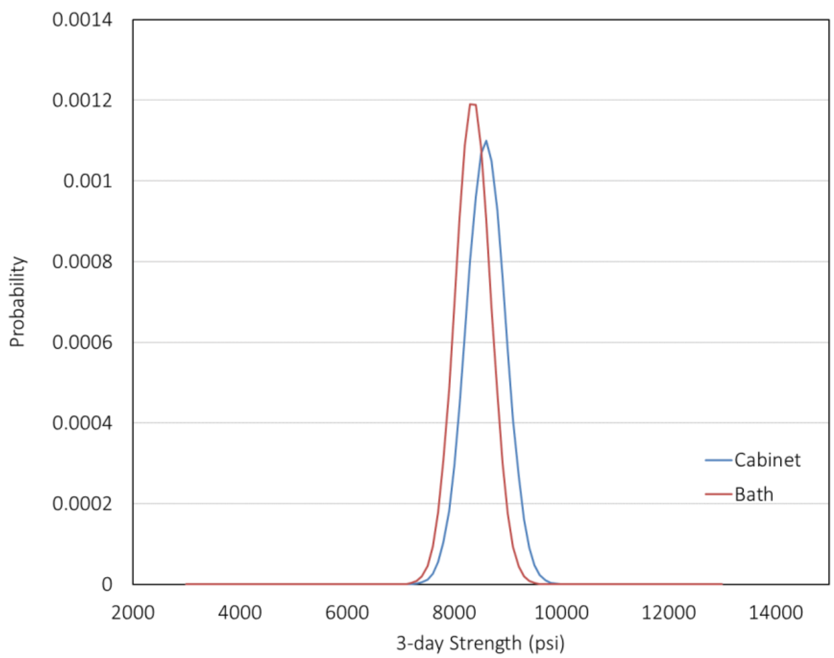


Figure 2-22. Normal distribution models for the 3-day strength (flowable consistency)

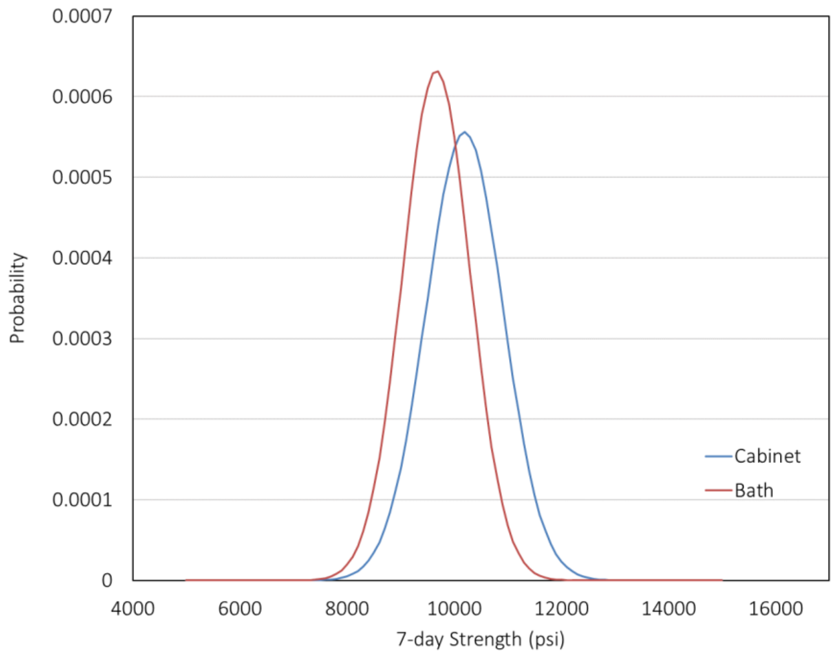


Figure 2-23. Normal distribution models for the 7-day strength (flowable consistency)

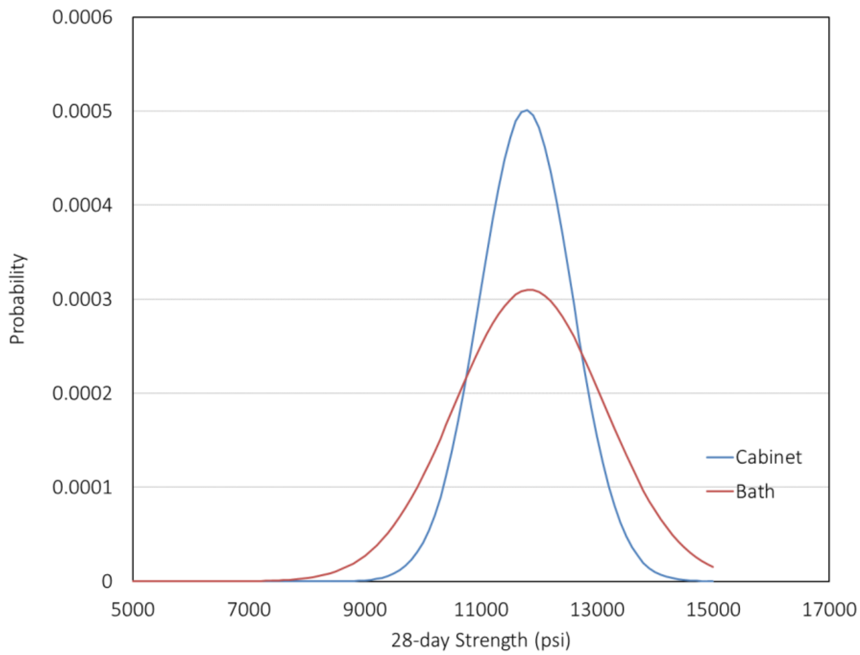


Figure 2-24. Normal distribution models for the 28-day strength (flowable consistency)

2.5 Round 3 Test Results

Round 3 is set for variability evaluation due to several factors. Mainly, factors like grout materials, specimen types, and strength test equipment were investigated. Table 2-2 shows the name of batches, grout materials used, and their mix consistency. The consistency was determined to satisfy the 9,000 psi strength requirement at 28-day.

Table 2-2. Grout materials in Round 3

Batch	Grout Material	Consistency
UAF-0814	Dayton Superior Sure-Grip® High Performance Grout	fluid
UAF-0821	Sakrete® Precision Non-shrink Grout	flowable
UAF-0828	Dayton Superior 1107 Advantage Grout	dry-pack
UAF-0904	MAPEI Planigrout 712	plastic
UAF-1016	BASF Masterflow® 928 High Strength Grout	plastic
DOT-0925	Dayton Superior Sure-Grip® High Performance Grout	fluid
DOT-1002	Sakrete® Precision Non-shrink Grout	flowable

The batch name is a combination of the agency who made specimens and the date when specimens were cast. For example, DOT&PF–NR technicians made the last two batches in the table. From each batch, 24 – 2"×2" cubes, 24 – ϕ4"×8" cylinder specimens, and one ϕ6"×12" cylinder were made. Half of cubes and ϕ4"×8" cylinders were transported to the DOT&PF–NR office for demolding at 24 hours after casting. They were cured and tested at the DOT&PF–NR office.

2.5.1 Cube and Cylinder Strengths

Compressive strengths measured at DOT&PF–NR and UAF were compared at 1-day, 3-day, 7-day, and 28-day. For cube strength, strength variation was compared with the variability limits. If the variation of three cubes was greater than 8.7% of the average, the corresponding column in a graph was colored in orange. If the variation of the selected two cubes was greater than 7.6% of the average of the two, the column was colored in red. Consequently, red columns indicate the cases where the variation limit was not satisfied. For cylinder specimens, no such variation limits are compared with test results. Columns in graphs were colored in blue if the test was done at DOT&PF–NR and green if done at UAF.

Figures 2-25 and 2-26 show compressive strength test results of cube and cylinder specimens from the UAF-0814 batch, respectively. Each graph compares DOT&PF–NR test results and UAF test results at 1-day, 3-day, 7-day, and 28-day. Strength test results of cube specimens in Figure 2-25 show similarity in their results between DOT&PF–NR and UAF. There was one case where the variation exceeded the 8.7% limit.

The cylinder strength results in Figure 2-26 also show similarity between the two test laboratories. The strength variation was greater than that from the cube specimens. The 28-day strength was around 8,000 psi, whereas it was over 10,000 psi from the cube specimens.

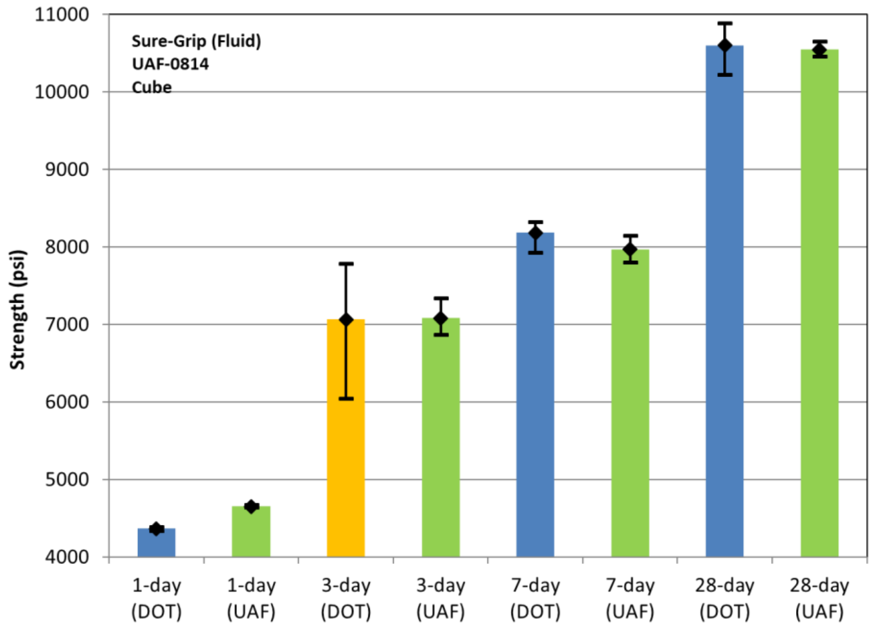


Figure 2-25. Compressive strength of Sure-Grip® (UAF-0814 batch, cube)

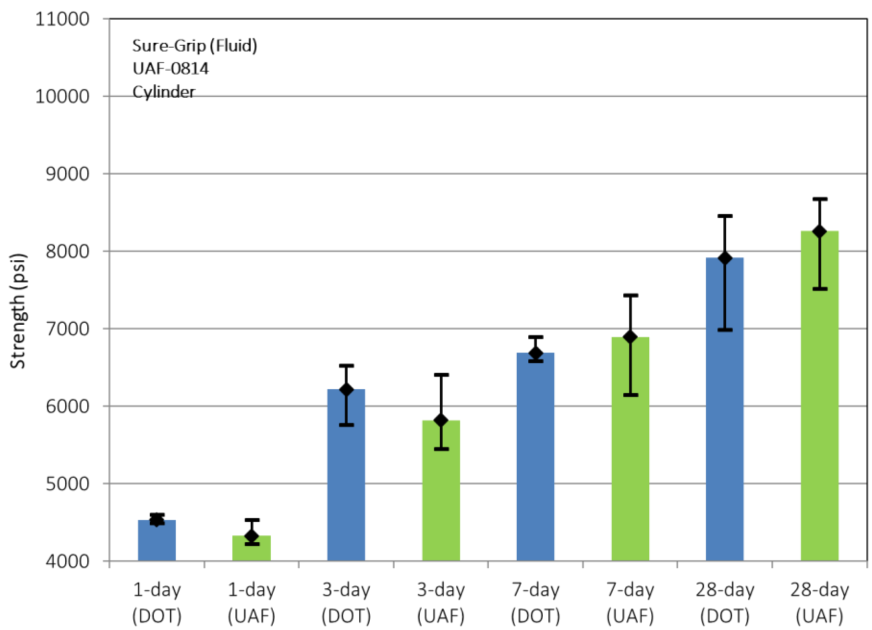


Figure 2-26. Compressive strength of Sure-Grip® (UAF-0814 batch, cylinder)

Figures 2-27 and 2-28 show strength test results of cube and cylinder specimens from the UAF-0821 batch. Figure 2-27 shows that all cases exceeded the 8.7% variability limit of three cubes. Furthermore, one case exceeded the 7.6 % variability limit of two cubes. The main cause of this exceeding variability limits was the consolidation method used to cast cube specimens. Since the mix consistency was flowable, the grout mix was puddled following ASTM C1107. If the grout mix is plastic, consolidation should be done with hand tamping following ASTM C109. The flowable mix of Sakrete® was not properly consolidated with puddling, and it made cube specimens vulnerable to having large variation in strength test results.

The cylinder strengths in Figure 2-28 show similarity between the two test laboratories. Moreover, strength variation was much smaller than cubes since cylinder specimens were better consolidated. The cylinder specimens were made following ASTM C39. Two lifts were used to make a cylinder, and each lift received 25 times of rodding. For Sakrete® (flowable), excessive strength variation in cube specimens was caused by improper consolidation of grout material.

Figures 2-29 and 2-30 are compressive strength of cube and cylinder specimens from the UAF-0828 batch. The dry-pack consistency was used in the mix of this grout material and hand tamping in ASTM C109 was employed to mold cube specimens. In Figure 2-29, there were three cases where the variation exceeded limits, and two out of three exceeded the 7.6% variability limit for two cubes (red columns). Nevertheless, the strength variation was exceptionally small for some cases.

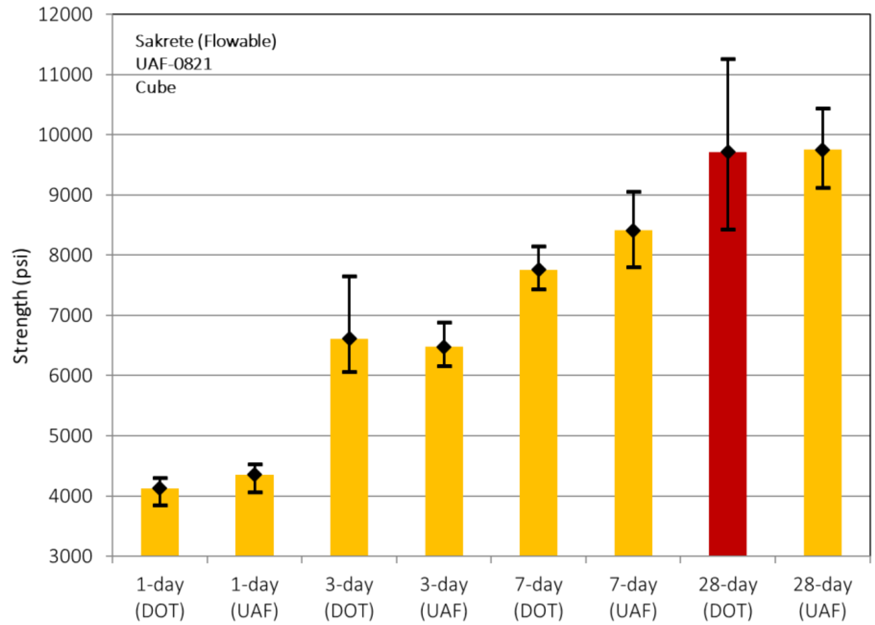


Figure 2-27. Compressive strength of Sakrete® (UAF-0821 batch, cube)

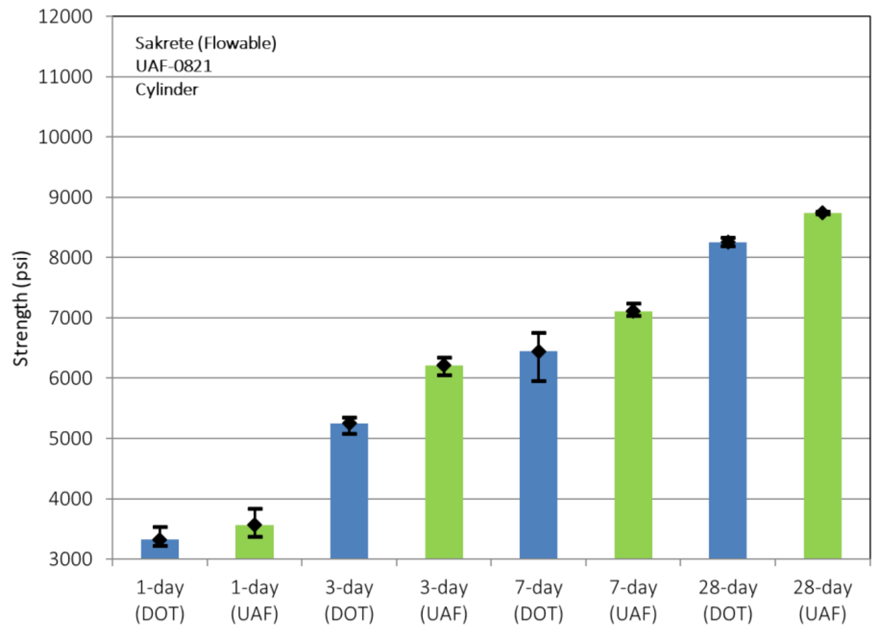


Figure 2-28. Compressive strength of Sakrete® (UAF-0821 batch, cylinder)

In Figure 2-30, the variation of cylinder strength was moderate and the average strength between DOT&PF–NR and UAF were comparable. Rodding grout material during molding cylinder specimens made the variation small, but the variation of 7-day test at UAF was exceptionally large.

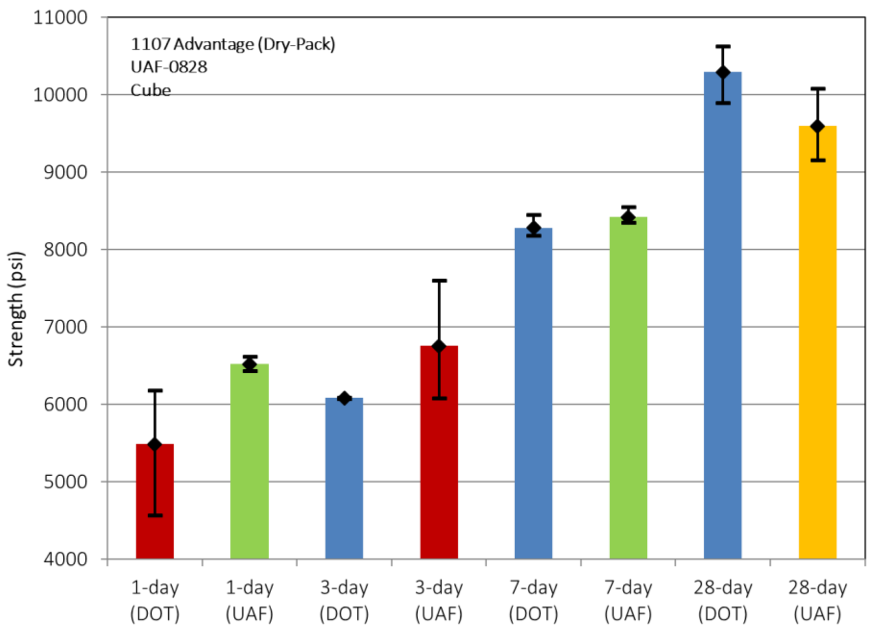


Figure 2-29. Compressive strength of Advantage (UAF-0828 batch, cube)

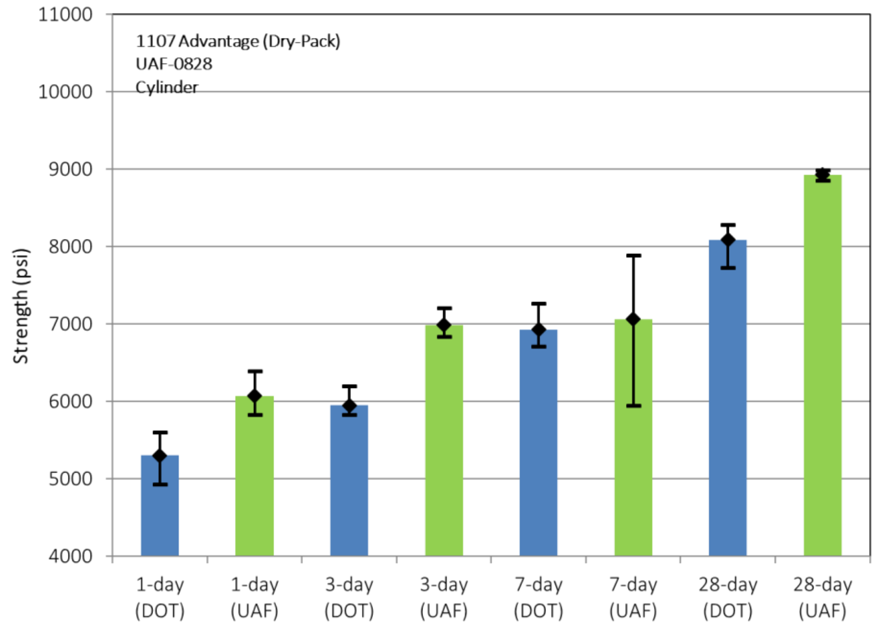


Figure 2-30. Compressive strength of Advantage (UAF-0828 batch, cylinder)

Figures 2-31 and 2-32 show compressive strength of cube and cylinder specimens from the UAF-0904 batch. Although the mix consistency was plastic, Planigrout was very workable when specimens were molded. In Figure 2-31, cube strengths were substantially high, and strength variation was small. Strength values between DOT&PF–NR and UAF were also comparable. It should be noted that the 7-day strength reached more than 9,000 psi. Cylinder strength in Figure 2-32 had a significantly small variation. Strengths between the two laboratories were also comparable.

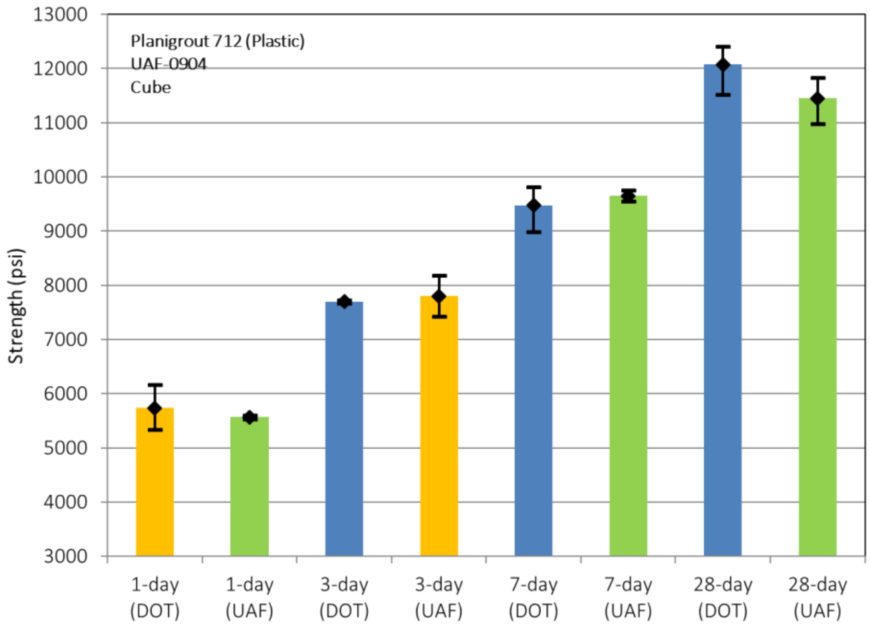


Figure 2-31. Compressive strength of Planigrout (UAF-0904 batch, cube)

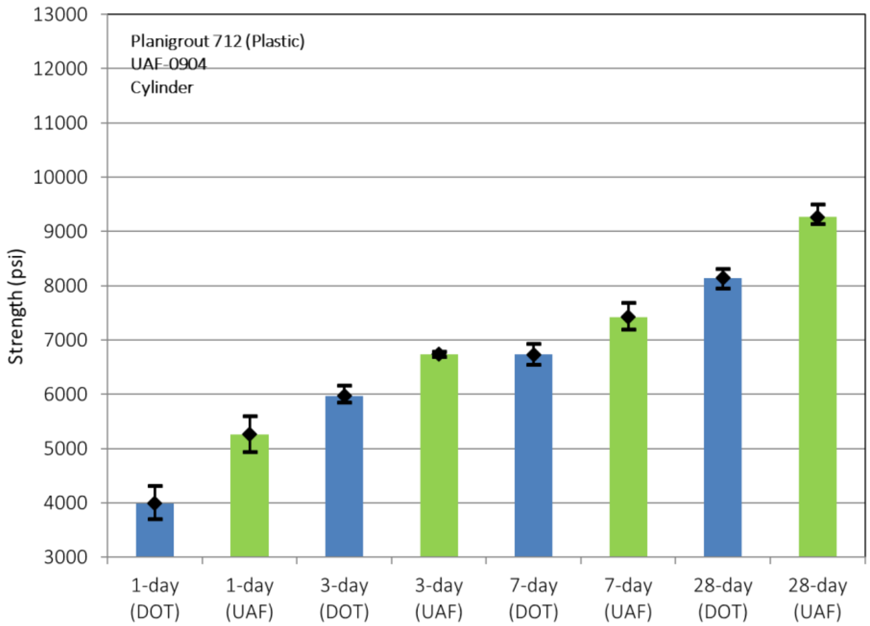


Figure 2-32. Compressive strength of Planigrout (UAF-0904 batch, cylinder)

Figures 2-33 and 2-34 show compressive strength of cube and cylinder specimens made from the UAF-1016 batch. In Figure 2-33, the 28-day strength of cube specimens reached more than 12,000 psi, which was the greatest among five tested grout materials. However, there were three cases where variation exceeded limits. Specifically, DOT&PF–NR test results at 3-day could not satisfy the 7.6% variability limit for two cubes. The mix consistency was plastic, and cube specimens needed a proper hand tamping for consolidation, which can be a cause of large strength variation. In Figure 2-34, the cylinder strength of this material was substantially smaller than other materials. Strength difference between the two laboratories was also large.

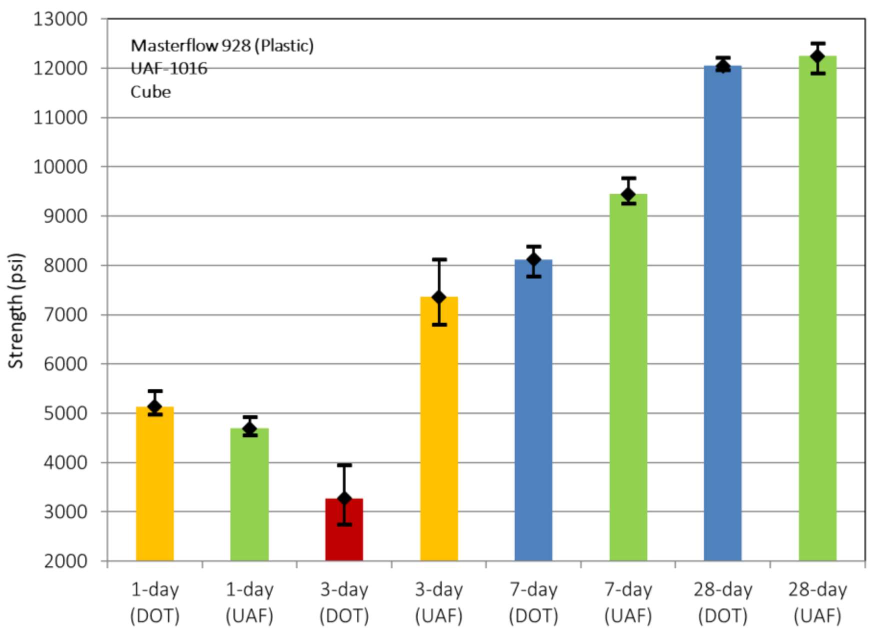


Figure 2-33. Compressive strength of Masterflow® (UAF-1016 batch, cube)

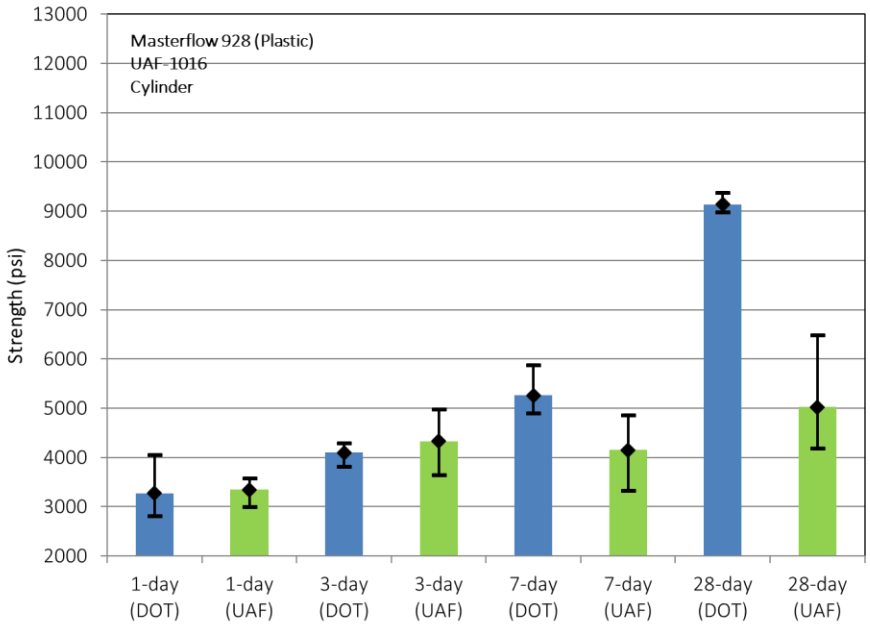


Figure 2-34. Compressive strength of Masterflow® (UAF-1016 batch, cylinder)

Figures 2-35 and 2-36 show compressive strength of cube and cylinder specimens from the DOT-0925 batch. The cube strengths between DOT&PF–NR and UAF in Figure 2-35 were comparable for the 3-day and 7-day strength, but the 28-day strength tested by DOT&PF– NR was smaller than 9,000 psi. In addition, the difference between the two test laboratories was significant, which was not seen in Figure 2-25. Given that the two batches, DOT-0925 and UAF-0814, used the same material, the difference could be caused by test equipment.

The comparison of cylinder strength in Figure 2-36 shows the test results from the two laboratories were comparable except the 28-day strength. The 28-day strength tested by DOT&PF–NR was substantially smaller than the results by UAF. As was proposed in the cube strength case, test equipment can be a cause of such different strength values. It should be also noted that the hardened surface of cylinder specimens can be rough at the top and it can cause a local failure that breaks out a wedge instead of core failure.

Figures 2-37 and 2-38 show compressive strength of cube and cylinder specimens made from the DOT-1002 batch. Three cases exceeded the 8.7% variability limit, but the test results from the two laboratories were comparable. When comparing Figure 2-37 with Figure 2-27, where specimens were made from the same material, the DOT-1002 batch developed strength with significantly less variation. The strength variation was reduced since the preparation of specimens, especially consolidation, got better. The cylinder strengths in Figure 2-38 were comparable between the two test laboratories.

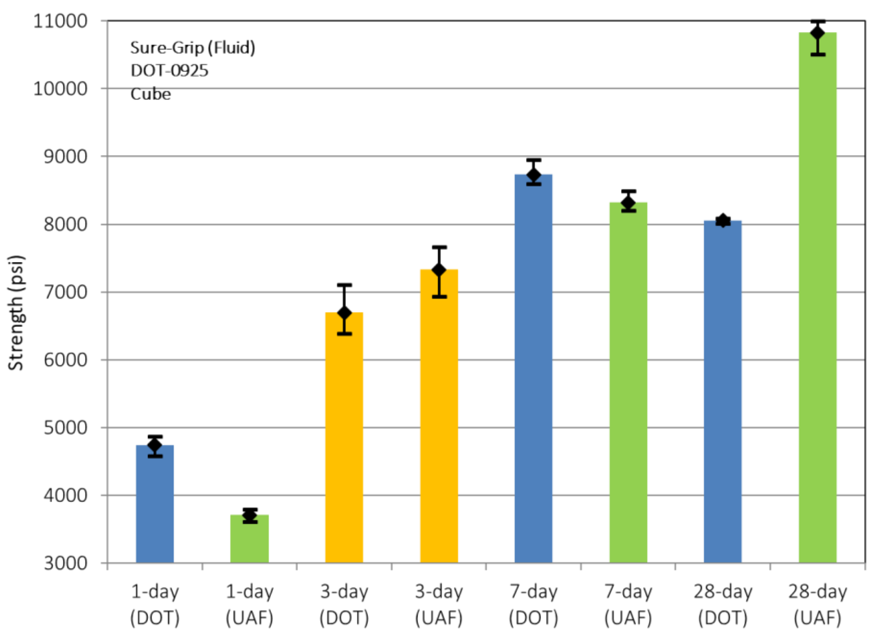


Figure 2-35. Compressive strength of Sure-Grip® (DOT-0925 batch, cube)

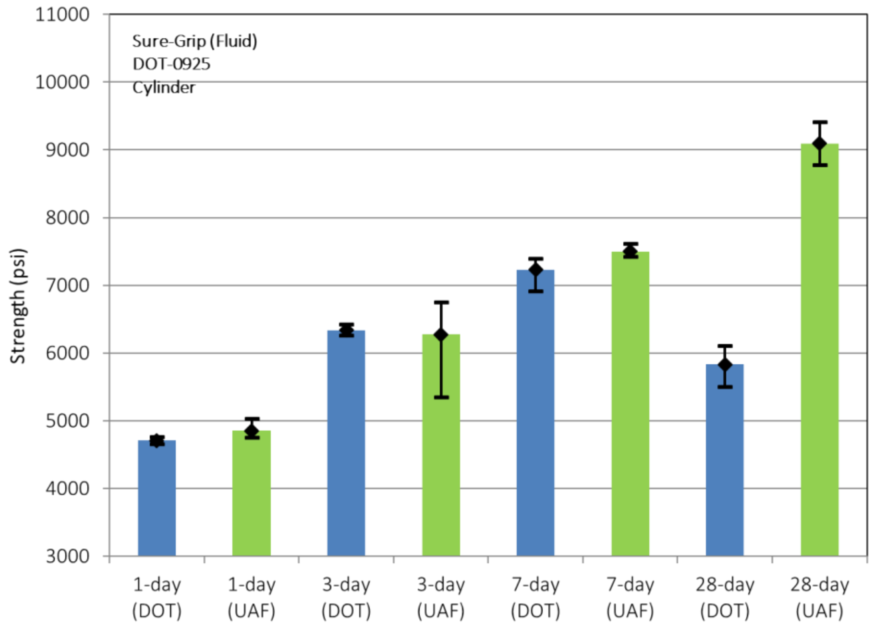


Figure 2-36. Compressive strength of Sure-Grip® (DOT-0925 batch, cylinder)

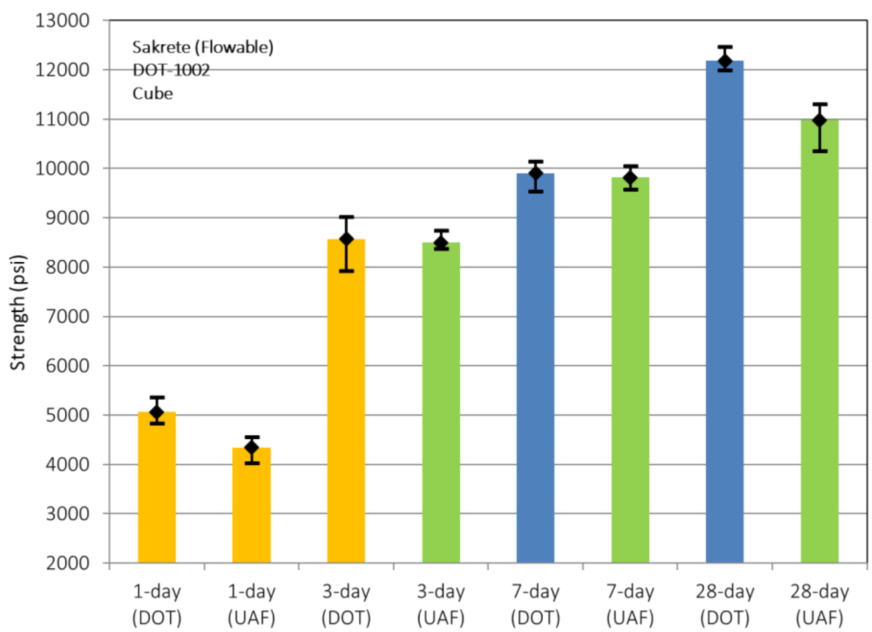


Figure 2-37. Compressive strength of Sakrete® (DOT-1002 batch, cube)

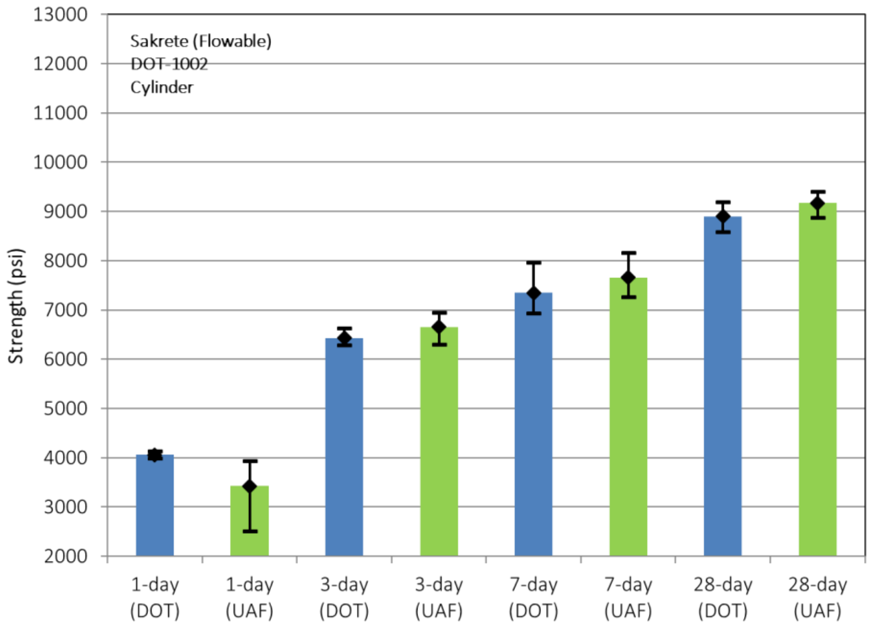


Figure 2-38. Compressive strength of Sakrete® (DOT-1002 batch, cylinder)

The 28-day cube strength test results show that two out of seven batches failed to satisfy the requirements in the DOT&PF Specifications. The variation exceeded limits in DOT&PF–NR test of the UAF-0821 batch, and the strength was less than 9,000 psi in DOT&PF–NR test of the DOT-0925 batch. The exceeding variation of the UAF-0821 batch could be caused by improper consolidation of specimens. The flowable consistency required only puddling, but the actual material needed hand tamping. The lower strength of the DOT-0925 batch could be caused while testing of specimens. Sure-Grip® grout has been tested several times at the DOT&PF–NR laboratory including the UAF-0814 batch test. There has been no occasion indicating such an abnormal result.

During mixing and molding specimens, it was noticed that the five grout materials have distinct characteristics. Two materials were different although the mix consistency was the same.

Eventually, a proper consolidation method should be selected based on the actual consistency. Given that, the researchers suggest gathering prior data on mixing and molding to decide a proper consolidation procedure.

Cylinder specimens over cube specimens may conceivably benefit from a uniform consolidation effort to every cylinder not depending on mix consistency. Following the same idea, hand tamping can be used as a uniform consolidation method for cube specimens for all mix consistency. Puddling can be used if hand tamping does not provide any consolidation effect. Since each grout material has a different working time, consolidation of all specimens should be completed within the specified working time.

2.5.2 Strength Factors between Cube and Cylinder Specimens

Comparison of compressive strengths of cube and cylinder specimens from five grout materials showed that the results from the two test laboratories, DOT&PF–NR and UAF, were comparable for most cases. Table 2-3 shows the mean, standard deviation, and coefficient of variation of test results after combining the results from the two laboratories. The coefficient of variation (cv) is the ratio of the standard deviation to the mean, that is cv = std/mean, which is a standard measure of dispersion of a probability distribution.

In Table 2-3, cv values for cylinder specimens are generally larger than those for cube specimens. The dispersion of cylinder strength is closely related to the preparation of cylinder specimens. It was observed that the top surface of a cylinder specimen tended to be swollen. Following the current practice of cylinder strength test in DOT&PF–NR, the top surface was capped with a rubber pad and a capping ring over rough surface. The cv for cylinder specimens can be reduced by flattening the top surface for better load distribution during the test.

There were some batches of which cv for cube specimens was larger than cv for cylinder specimens. For the UAF-0821 and UAF-0828 batches, the greater cv values for cube specimens could be caused by improper consolidation of cube specimens. Some materials required more care in consolidation than practiced in typical procedure.

Table 2-3. Compressive strength test result in Round 3

Batch	**Test Day**	**Cube**			**Cylinder**		
		mean	**std**	**cv**	**mean**	**std**	**cv**
		psi	**psi**		**psi**	**psi**	
UAF-0814	3	7,071	595	0.0842	6,021	466	0.0774
	7	8,182	223	0.0273	6,793	450	0.0663
	28	10,573	229	0.0216	8,089	680	0.0840
UAF-0821	3	6,546	616	0.0941	5,734	544	0.0949
	7	8,084	580	0.0717	6,777	461	0.0680
	28	9,732	1,001	0.1028	8,500	270	0.0318
UAF-0828	3	6,419	614	0.0957	6,468	595	0.0921
	7	8,349	139	0.0166	6,996	668	0.0955
	28	9,946	537	0.0540	8,508	505	0.0594
UAF-0904	3	7,751	246	0.0317	6,356	436	0.0686
	7	9,564	300	0.0313	7,076	428	0.0605
	28	11,763	537	0.0457	8,704	639	0.0734
UAF-1016	3	5,314	2,314	0.4354	4,213	468	0.1110
	7	8,782	773	0.0880	4,703	851	0.1808
	28	12,148	248	0.0204	7,079	2,395	0.3384
DOT-0925	3	7,014	480	0.0685	6,305	514	0.0815
	7	8,527	272	0.0319	7,364	239	0.0325
	28	9,440	1,527	0.1618	7,463	1,809	0.2425

Batch	Test Day	Cube			Cylinder		
		mean	**std**	**cv**	**mean**	**std**	**cv**
		psi	**psi**		**psi**	**psi**	
DOT-1002	3	8,532	389	0.0456	6,542	267	0.0409
	7	9,858	256	0.0260	7,500	481	0.0642
	28	11,578	758	0.0655	9,036	297	0.0328

NOTE: std is the standard deviation; cv is the coefficient of variation.

For the same grout material, the compressive strengths of cube and cylinder specimens were different. Due to the different size and shape, the failure mode of the two specimen types are different, and the 2″×2″ cube strength is generally greater than ϕ4″×8″ cylinder strength. In Table 2-4, the mean, standard deviation, and cv values are summarized for each grout material tested. Sure-Grip® and Sakrete® were used in two batches, and the results were combined. In other rounds of the test, more cube specimens from Sure-Grip® and Sakrete® were tested and those results were also combined in the calculation of mean and standard deviation of those two materials. For the other materials, the mean and standard deviation are the same as in Table 2-3.

Table 2-4. Compressive strength test result per grout material

Grout	Test Day	Cube			Cylinder			Remark
		mean	**std**	**cv**	**mean**	**std**	**cv**	
		psi	**psi**		**psi**	**psi**		
Sure-Grip®	3	7,721	418	0.054	6,163	490	0.080	data from other rounds for cube; combine UAF-0814, DOT-0925 for cylinder
	7	8,912	594	0.067	7,079	455	0.064	
	28	10,807	706	0.065	7,776	1,343	0.173	
Sakrete®	3	7,886	641	0.081	6,138	588	0.096	use DOT-1002 and Round 4 for cube; combine UAF-0821, DOT-1002 for cylinder
	7	9,466	463	0.049	7,139	587	0.082	
	28	10,935	559	0.051	8,768	389	0.044	

Grout	Test Day	Cube			Cylinder			Remark
		mean	**std**	**cv**	**mean**	**std**	**cv**	
		psi	**psi**		**psi**	**psi**		
Advantage	3	6,419	614	0.096	6,468	595	0.092	
	7	8,349	139	0.017	6,996	668	0.096	
	28	9,946	537	0.054	8,508	505	0.059	
Planigrout	3	7,751	246	0.032	6,356	436	0.069	
	7	9,564	300	0.031	7,076	428	0.061	
	28	11,763	537	0.046	8,704	639	0.073	
Masterflow®	3	5,314	2,314	0.435	4,213	468	0.111	
	7	8,782	773	0.088	4,703	851	0.181	
	28	12,148	248	0.020	7,079	2,395	0.338	

NOTE: std is the standard deviation; cv is the coefficient of variation.

Table 2-5 provides the factors used to convert cube strength to cylinder strength. The cv was used as an accuracy measure to select mean strength from Table 2-4 for the calculation of factors. In addition, analysis assumes that each test day is independent. For a given cv, either 9% or 7%, test day was selected only if the cv values of cube and cylinder specimens were less than the given cv. Then, a factor was calculated using the mean strength at that test day. If more than one test day is viable, an average value of factors was used in Table 2-5.

Table 2-5. Factors for compressive strength per grout material

Grout Material	cv considered	
	< 9%	**< 7%**
Sure-Grip®	0.796	0.794
Sakrete®	0.778	0.802
Advantage	0.855	0.855
Planigrout	0.767	0.780
Masterflow®	NA	NA

NOTE: cv is the coefficient of variation.

It should be noted that factors for Sure-Grip® and Sakrete® are more reliable since they were calculated based on larger sets of data. For Advantage and Planigrout grouts, the factors were calculated from a small set of data. The cv values were too big to calculate a factor for Masterflow® grout.

2.5.3 Elastic Modulus of Grout Materials

The elastic modulus of grout materials was evaluated from the stress-strain relationship measured from a ϕ6"×12" cylinder specimen following the ASTM C469: *Standard Test Method for Static Modulus of Elasticity and Poisson's Ratio of Concrete* (ASTM 2014a). The same cylinder was used to measure 7-day and 28-day stiffness.

Figure 2-39 shows 7-day and 28-day stress-strain measurement of Sure-Grip® grout (UAF-0814 batch). At each test age, loading-unloading was repeated three times and the 2nd and 3rd loading results were used in the figure. In addition, a trend line with R-value was drawn over the measured stress-strain. The R-value was either 1.0 or 0.99, which indicated a linear relationship of measured stress-strain values. Therefore, the slope of a trend line corresponds to the elastic modulus. Compared to the 7-day stiffness, the 28-day stiffness slightly increased.

Figure 2-40 shows measured stress-strain values from the specimen made from Sakrete® grout (UAF-0821 batch). Measured stress-strain values were in a linear relationship so that the slope can represent the elastic modulus. A slight increase of the 28-day stiffness can be also seen compared to the 7-day stiffness.

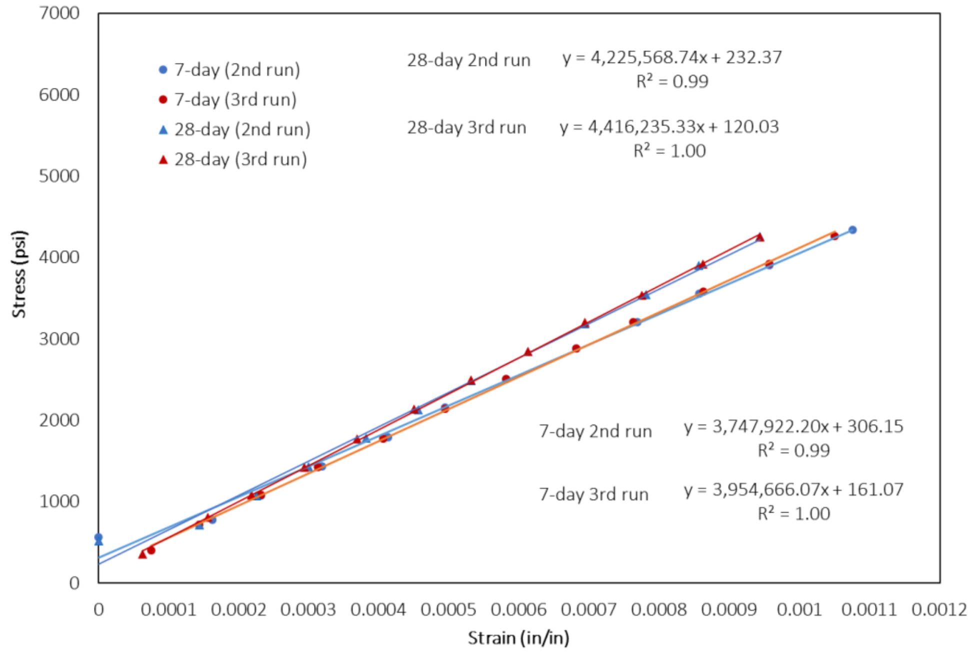


Figure 2-39. Stress-strain relationship of Sure-Grip® (UAF-0814 batch)

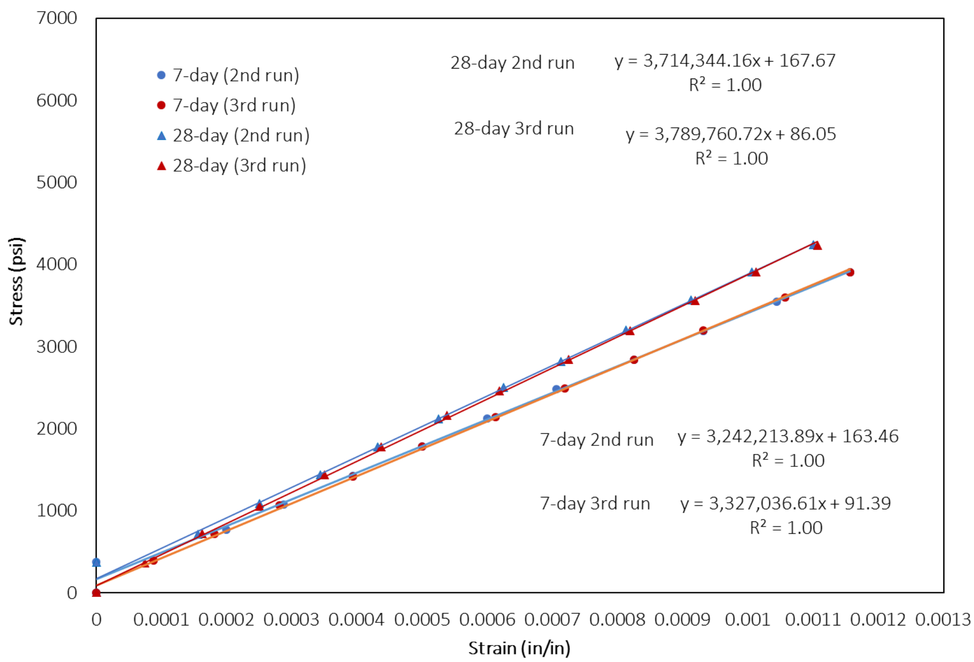


Figure 2-40. Stress-strain relationship of Sakrete® (UAF-0821 batch)

Figure 2-41 shows measured stress-strain values and trend lines for the specimen made from the Advantage grout. The measured stress-strain values were in a linear relationship. There was a very small increase in stiffness at 28-day results.

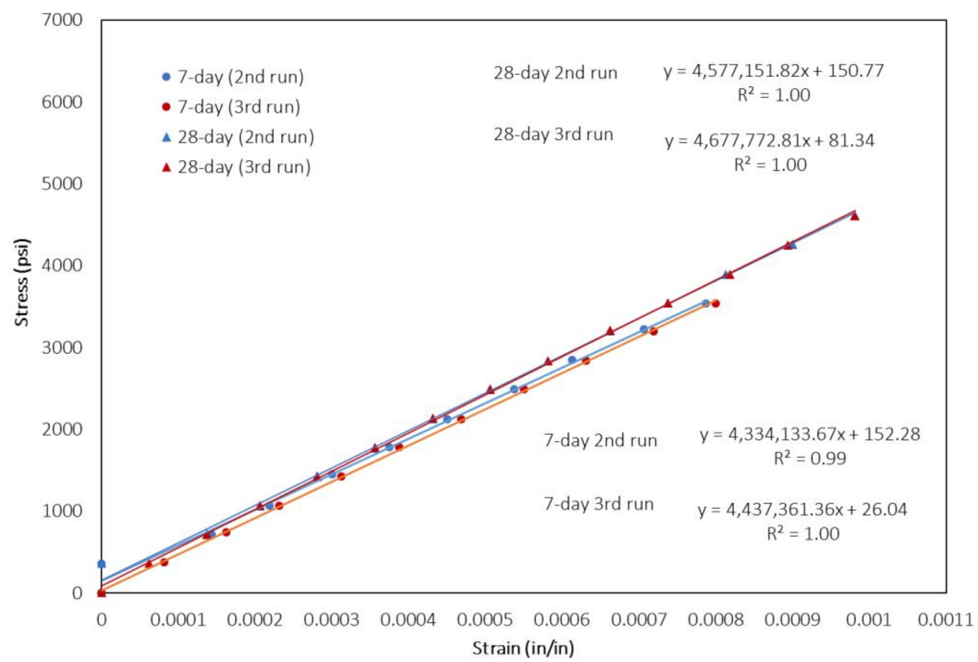


Figure 2-41. Stress-strain relationship of Advantage (UAF-0828 batch)

Figure 2-42 shows measured stress-strain values and trend lines for the specimen made from Planigrout. A slight increase of the 28-day stiffness can be observed in the figure compared to the 7-day stiffness.

To summarize, the elastic modulus and cube strength of grout materials are provided in Table 2-6. The elastic modulus is the average of two measurements at each test age, and the cube strengths were taken from Table 2-4.

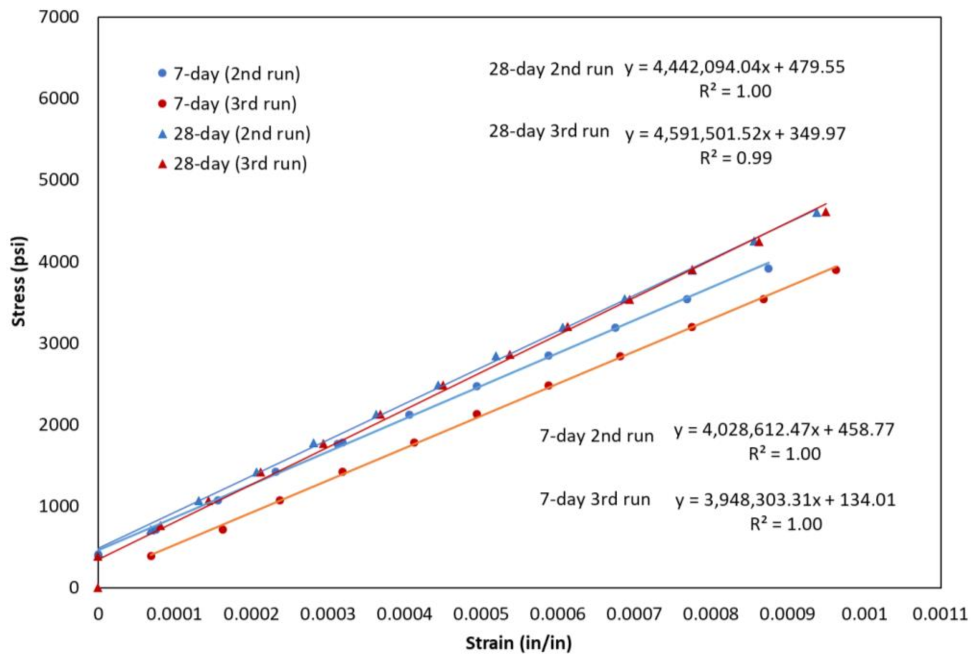


Figure 2-42. Stress-strain relationship of Planigrout (UAF-0904 batch)

Table 2-6. Elastic modulus and compressive strength of grout material

Grout	***Test Day***	***Elastic Modulus***	***Cube Strength***
		psi	**psi**
Sure-Grip®	7	3,851,294	8,912
	28	4,320,902	10,807
Sakrete®	7	3,284,625	9,466
	28	3,752,052	10,935
1107 Advantage	7	4,455,643	8,349
	28	4,557,567	9,946
Planigrout	7	3,988,458	9,564
	28	4,516,798	11,763

2.6 Round 4 Test Results

Round 4 investigated the effects of initial curing and storing condition of cube specimens. The compressive strengths of cube specimens mixed by a mixing paddle were also compared with those made by a laboratory mixer or a mortar mixer.

Table 2-7 demonstrates seven grout batches in Round 4 with materials and the number of cube specimens tested. Two grout materials, Sure-Grip® in fluid consistency and Sakrete® in flowable consistency, were used, and several different initial curing conditions were investigated. For elevated temperature cases, molds and mixing water were stored at an elevated temperature before molding, and the molds were stores in a cooler or an environmental chamber under an elevated temperature after molding. Cubes were demolded at 48 hours after casting for some cases. For paddle mixing, cubes were cured in a moisture cabinet and a water bath in order to study combined effect with curing condition as was done in Round 2.

2.6.1 Initial Curing Condition

Figure 2-43 shows the 3-day, 7-day, and 28-day strengths of Sure-Grip® cubes from the UAF-1121 and UAF-1205 batches. Cube molds and mixing water were stored in an environmental chamber at 94 – 98°F before molding. After molding, each mold was completely wrapped with wet cloths, tucked in plastic bags, and stored in a cooler. Cubes in these molds were demolded at 48 hours after casting. After demolding, cubes were cured in a water bath. In addition, three reference cubes were made from each batch, and their molds were stored in a moisture cabinet. The reference cubes were demolded at 24 hours after casting and cured in a water bath.

Table 2-7. Batches for Round 4

Batch	Grout Material	Number of Cube Specimens	Remark
UAF-1121	Sure-Grip® (fluid)	3+9	Elevated Temperature
UAF-1205	Sure-Grip® (fluid)	3+9	Elevated Temperature
UAF-0218	Sure-Grip® (fluid)	12+12	Elevated Temperature
UAF-0319	Sure-Grip® (fluid)	12+12	Paddle Mixing (Method B)
UAF-0321	Sure-Grip® (fluid)	12+12	Paddle Mixing (Method A)
UAF-0415	Sakrete® (flowable)	12+12	Paddle Mixing (Method A)
UAF-0422	Sakrete® (flowable)	12+12	Paddle Mixing (Method A)

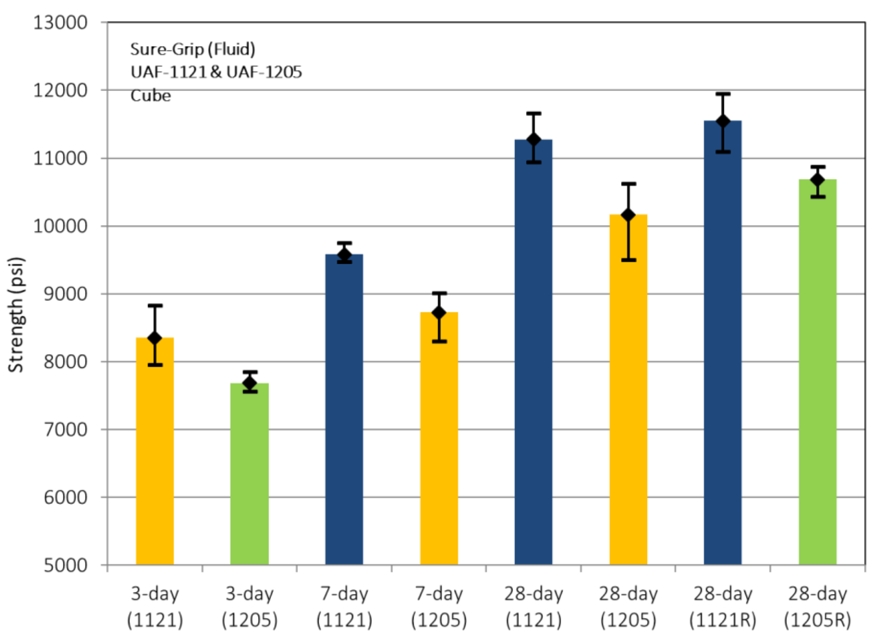


Figure 2-43. Compressive strength of Sure-Grip® cubes initially cured at elevated temperature (UAF-1121 and UAF-1205 batches)

In Figure 2-43, dark blue bars represent the UAF-1121 batch, and green bars represent the UAF-1205 batch. Orange bars indicate the cases where variation exceeded the 8.7% limit for three cubes. The last two bars labeled as 1121R and 1205R are results from reference cubes. In each batch, the 28-day strength was close to the strength of reference cubes, which indicates minor effect of elevated temperature during initial curing and delayed demolding of Sure-Grip® cubes. Although the overall strength of the UAF-1121 batch was greater than the strength of the UAF-1205 batch, the difference was not so significant to require further investigation. A comparison between the UAF-B-0522 batch (Figure 2-14) and the UAF-B-0911 batch (Figure 2-15) showed that such differences in compressive strength could be found in cube specimens made by the same researcher.

Figure 2-44 shows compressive strength test results of the UAF-0218 batch. Molds and mixing water were stored in an environmental chamber at 81°F. 24 cubes (8 molds) were molded and the molds were stored in an environmental chamber at 81°F before demolding. 12 cubes were initially cured for 24 hours before demolding, and the other 12 cubes were cured for 48 hours. After demolding, all cubes were stored in a water bath. These cubes were prepared to investigate one factor: duration of initial curing before demolding. Among 12 cubes for each group, 2 sets of three cubes were used for 28-day strength test. Between dark blue bars (24 hours of initial curing) and green bars (48 hours of initial curing), no significant difference can be found. Therefore, the compressive strength of Sure-Grip® (fluid consistency) cube specimens had no noticeable difference between the cubes initially cured for 24 hours and 48 hours.

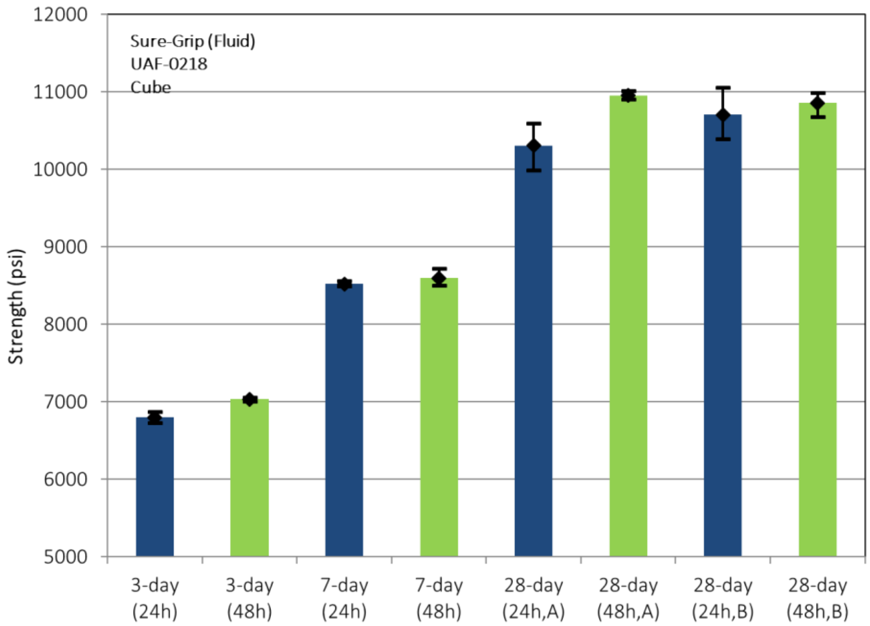


Figure 2-44. Compressive strength of Sure-Grip® cubes with different demolding time (UAF-0218 batch)

2.6.2 Paddle Mixing

Figure 2-45 shows compressive strength test results of the UAF-0319 and UAF-0321 batches. A paddle mixer mixed these batches. Grout material and mixing water were mixed in a bucket by a mixing paddle connected to a drill. Paddle mixing is a convenient way to yield a small amount of grout without using a mortar mixer. From each batch, 24 cubes were molded. The half were cured in a moisture cabinet, and the other half were cured in a water bath. The setup was similar to Round 2. The UAF-0321 batch was mixed following a recommended procedure in section 1.3.2, whereas the UAF-0319 batch was mixed in a more uncontrolled way.

Figure 2-45 shows that the UAF-0319 batch had lower strength at 3-day, but both batches reached comparable 28-day strengths, whether cubes were cured in a moisture cabinet or in a water bath. Table 2-8 compares the mean and standard deviation of cube strength with the strength of cubes mixed in a laboratory mixer or in a mortar mixer. Mean strengths were comparable between the two mixing methods. It implies that paddle mixing can produce grout that satisfies strength requirement. Although cubes from the UAF-0319 batch had comparable strength, the mixing method used for this batch is not recommended. For paddle mixing, the recommended procedure in section 1.3.2 will produce cubes with better quality.

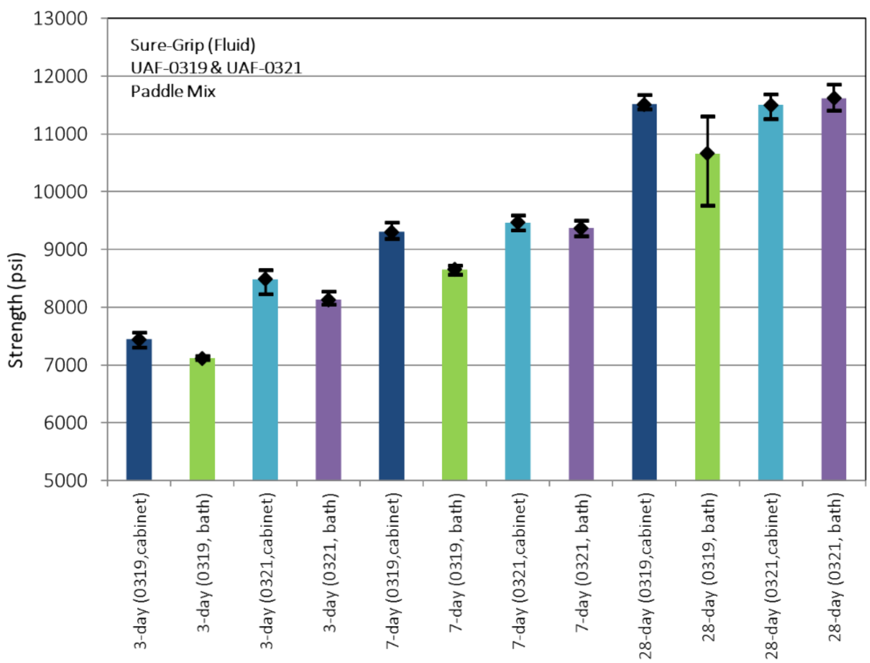


Figure 2-45. Compressive strength of Sure-Grip® cubes made from paddle mixing (UAF-0319 and UAF-0321 batches)

Table 2-8. Mean and standard deviation of cube strength (paddle mixing, Sure-Grip®)

Test Day	Paddle mixing			Lab mixer and mortar mixer		
	Mean (psi)	**std (psi)**	**cv**	**Mean (psi)**	**std (psi)**	**cv**
3	8,098	580	0.0716	7,721	418	0.0541
7	9,199	351	0.0382	8,912	594	0.0667
28	11,324	551	0.0487	10,807	706	0.0654

NOTE: std is the standard deviation; cv is the coefficient of variation.

The applicability of paddle mixing was examined with another grout material. Figure 2-46 shows the compressive strength test results of cubes from the UAF-0415 and UAF-0422 batches using Sakrete® (flowable consistency). The two batches used a paddle mixer to mix grout material with water following the recommended procedure in section 1.3.2. From the UAF-0415 batch, 12 cubes were cured in a moisture cabinet, and the other 12 cubes were cured in a water bath in order to examine effect from curing condition as was executed in Round 2 for Sure-Grip®. Two test results, the 3-day and 7-day strengths of cubes cured in a moisture cabinet, showed that variation exceeded the 8.7% limit for three cubes. These cases are colored in orange in Figure 2-46. There was no significant difference in strength between cubes cured in a moisture cabinet and in a water bath.

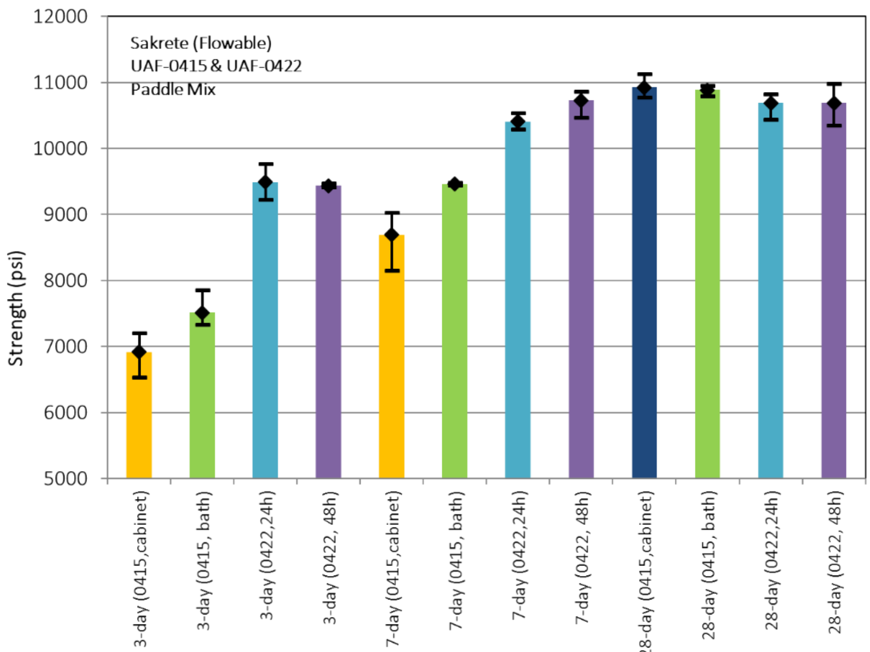


Figure 2-46. Compressive strength of Sakrete® cubes made from paddle mixing (UAF-0415 and UAF-0422 batches)

For the UAF-0422 batch, cube molds and mixing water were stored in an environmental chamber at 81°F before mixing. After molding, molds were stored back in the environmental chamber for initial curing. 12 cubes were initially cured for 24 hours and the other 12 cubes were cured for 48 hours. After demolding, cubes were cured in a water bath.

Figure 2-46 shows that the 28-day strength of cubes from the two batches were comparable. It was observed that the 3-day and 7-day strengths of cubes from the UAF-0422 batch were significantly greater than the UAF-0415 batch. Sakrete® gained higher early strength from the elevated temperature during initial curing. Between 24-hour and 48-hour initial curing, there was no significant difference in strength.

Table 2-9 compares the mean and standard deviation of strength between cubes mixed with different methods. The paddle mixing case used all data in Figure 2-46. The mortar mixer case used data from Round 3. Mean values from the two mixing methods were comparable, which implies that paddle mixing can be used to make Sakrete® cube specimens of which strength is comparable to cubes whose batch is mixed by a mortar mixer.

Table 2-9. Mean and standard deviation of strength (paddle mixing, Sakrete®)

Test Day	**Paddle mixing**			**Mortar mixer**		
	Mean (psi)	**std (psi)**	**cv**	**Mean (psi)**	**std (psi)**	**cv**
3	8,339	1,216	0.1458	8,532	389	0.0456
7	9,823	869	0.0885	9,858	256	0.0260
28	10,797	218	0.0202	11,578	758	0.0655

NOTE: std is the standard deviation; cv is the coefficient of variation.

2.7 Round 5 Test Results

Round 5 evaluated several material properties of Polyester Polymer Concrete (PPC), including compressive strength, elastic modulus, and bond strength. The compressive strength was measured from 2″×2″ cubes and ϕ4″×8″ cylinders at 3-day, 7-day, and 28-day. Figures 2-47 and 2-48 show compressive strength test results of cubes and cylinders, respectively. Table 2-10 summarizes the measured strengths. For cube specimens, the 7-day strength was similar to the 3-day strength. The 28-day strength was slightly greater than the 7-day strength. For cylinder specimens, the 7-day strength was slightly greater than the 3-day strength. The 28-day strength was similar to the 7-day strength. The compressive strength of PPC is specified as 7,000 psi in the product data sheet (KwikBond Polymers 2018), and a laboratory test results provided by the manufacturer showed that the 1-day strength could reach 7,168 psi (MTL 2018). However, the measured cube strength was lower than 7,000 psi.

Table 2-10. PPC Compressive Strength Test Results

Test day	specimen1	specimen2	specimen3	mean	cv	remark
	psi	psi	psi	psi		
3	6,370	6,094	6,263	6,242	0.022	cube
	6,139	6,033	5,901	6,024	0.020	
7	5,573	6,099	5,784	5,818	0.046	
	6,350	6,299	6,235	6,295	0.009	
28	6,715	6,813	6,840	6,789	0.010	
	6,340	6,409	6,256	6,335	0.012	
3	5,843	5,734	5,622	5,733	0.019	cylinder
	5,641	5,690	5,565	5,632	0.011	
7	6,172	6,168	5,588	5,976	0.056	
	5,999	5,926	5,901	5,942	0.009	

28	5,942	5,954	5,872	5,922	0.007	
	6,215	6,325	5,982	6,174	0.028	

NOTE: cv is the coefficient of variation.

The cylinder strength was less than the cube strength, but the difference was small. There were two cases where the coefficient of variation (cv) was greater than 4%. For other cases, the cv was less than or equal to 2.8%. The PPC was made by mixing pre-packaged ingredients. Therefore, the strength variation caused by ingredient differences is minimal. To reduce the strength variation, mix design should be modified to produce an optimal concrete.

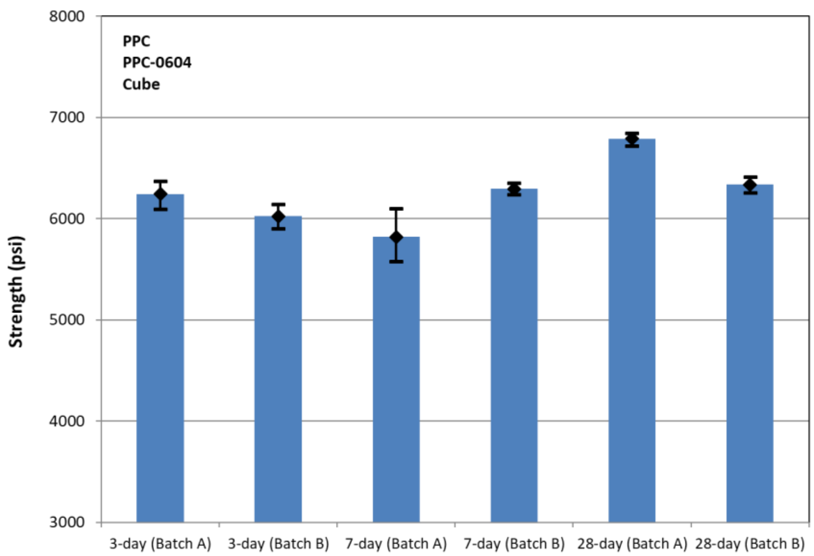


Figure 2-47. Compressive strength of PPC cubes

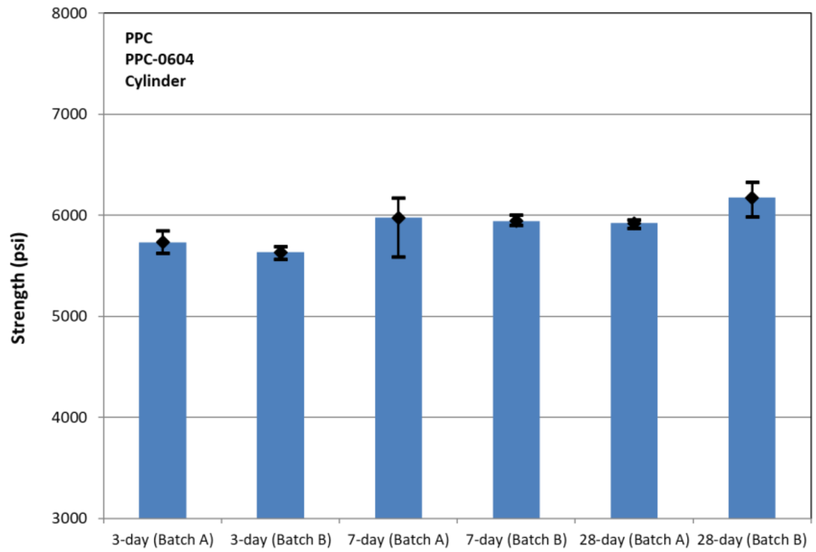


Figure 2-48. Compressive strength of PPC cylinders

Slant shear test is a convenient way of measuring bond strength between two different materials. When a force P is applied to a slant shear specimen in Figure 2-49, it can be decomposed into a normal force (N) and a shear force (S) on the interface. The amount of forces are:

$$\begin{aligned} N &= P \sin 30^\circ \\ S &= P \cos 30^\circ \end{aligned} \tag{2-1}$$

The interfacial area is:

$$A = \frac{\pi}{4}(4in)(8in) = 25.13in^2 \tag{2-2}$$

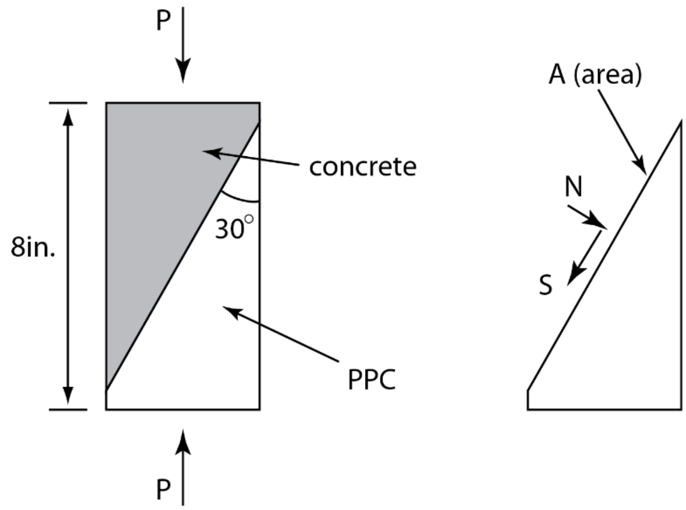


Figure 2-49. Cylinder specimen in slant shear test

Table 2-11 summarizes the measured bond strength (*P/A*). Also, shear stress (*S/A*) is given. It should be noted that the shear strength is not the same as the measured shear stress because of the non-zero normal force. A comparison of bond strength did not indicate significant changes from 7-day to 28-day. The average bond strength from the two batches and the two test ages was 2,630 psi.

The bond strength at the cold temperature of -40°F increased substantially compared to the bond strength at room temperature (74°F). The strength was 2.05 times larger in the PPC-0604A batch, and 1.67 times larger in the PPC-0604B batch. Adhesive forces between the two materials at the interface increased due to the cold temperature.

Test results also showed that shear stress at the peak was considerably smaller for some specimens: specimen 3 in the PPC-0604A batch and specimen 2 in the PPC-0604B batch at 7-day, specimens 1 and 3 in the PPC-0604A batch at 28-day. This reduced stress was resulted from weak bonding at the interface surface. Figure 2-50 compares the interface surfaces of the specimens. When the bond strength was greater, the interface surface was rough, which indicates better bonding between PPC and concrete. The surface was rather smooth, when the bond strength was smaller. It was recommended to use sandblasting on concrete surface before applying the primer. In the present test, however, the primer was spread on dried concrete surface without sandblasting to represent the current practice for non-shrink, cementitious grout materials. If sandblasting is used, the bond strength may increase, and the variation of bond strength can reduce.

Table 2-11. Slant shear test results (psi)

Batch	Test Day	stress	specimen1	specimen2	specimen3	Average
PPC-0604A	7	P/A	2,842	2,993	2,300	2,712
		S/A	2,461	2,592	1,992	
	28	P/A	2,289	2,669	2,298	2,419
		S/A	1,982	2,312	1,990	
	28 (-40°F)	P/A	5,458	4,820	4,600	4,960
		S/A	4,727	4,175	3,984	
PPC-0604B	7	P/A	3,382	1,964	2,574	2,640
		S/A	2,929	1,701	2,229	
	28	P/A	2,957	2,714	2,572	2,748
		S/A	2,561	2,350	2,227	
	28 (-40°F)	P/A	5,298	3,984	4,511	4,598
		S/A	4,589	3,451	3,907	

The stress-strain relationship of PPC was measured during the compressive strength test of cylinder specimens, specimen 2 and specimen 3, from each batch and test age in Table 2-10. On one side of a cylinder, 4-inch spacing was marked with adhesive tapes as shown in Figure 2-51. A laser extensometer was used to measure the distance change between marking tapes as compressive force was applied. Strain was calculated based on the measured distance change.

(a) PPC-0604B batch, Specimen 1 (b) PPC-0604B batch, Specimen 2

Figure 2-50. Interface surface between two materials after test

Figure 2-51. Laser extensometer for measuring deformation

Figure 2-52 shows stress-strain curves from the four cylinder specimens tested for the 3-day strength. Under compression, the PPC cylinders deformed more than a strain of 0.8% at the peak stress, which is much greater than a typical strain of 0.2% of concrete. The PPC cylinders substantially deformed after the peak strength. After the peak stress, when stress reached about 50% of the peak strength, the residual strain was 2.5% – 6.3%.

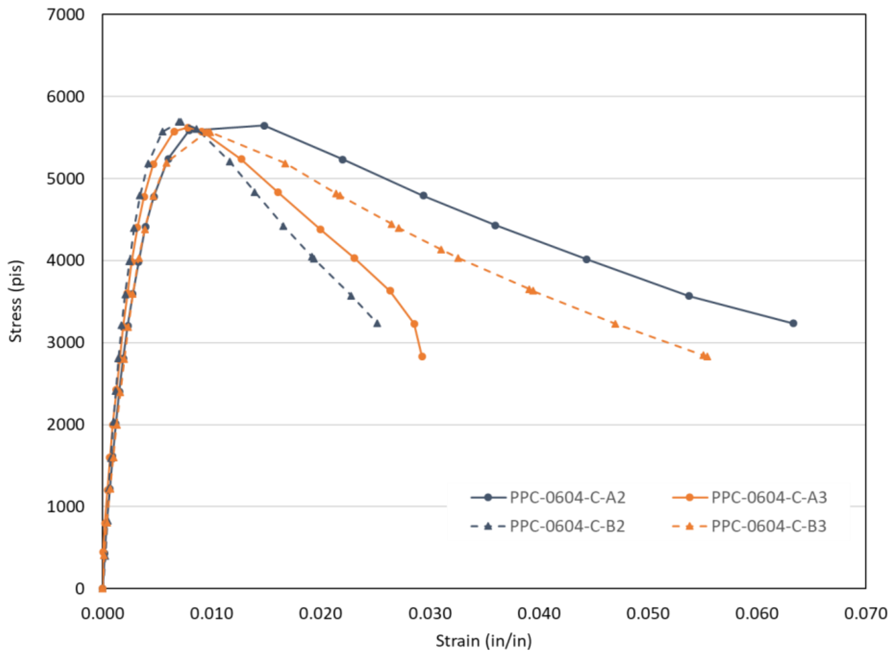


Figure 2-52. Stress-strain of cylinders (3-day)

Figures 2-53 and 2-54 show the stress-strain curves measured from specimens for the 7-day and the 28-day strengths, respectively. The trend of curves was similar to the ones from the 3-day strength. The strain at the peak stress was around 0.8%, and the residual strain varied from 2.4 – 6.3%, which were close to values from the 3-day strength test.

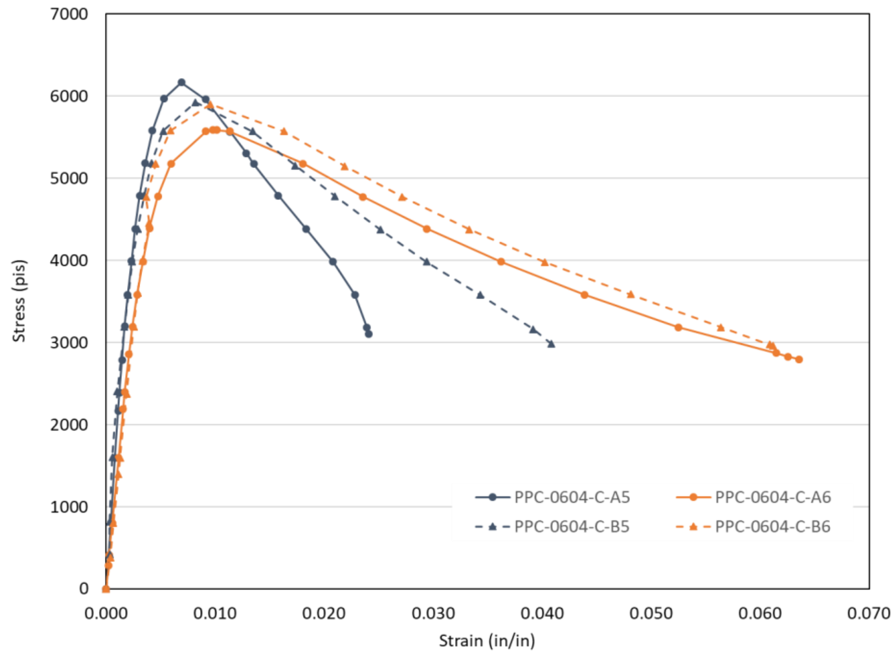


Figure 2-53. Stress-strain of cylinders (7-day)

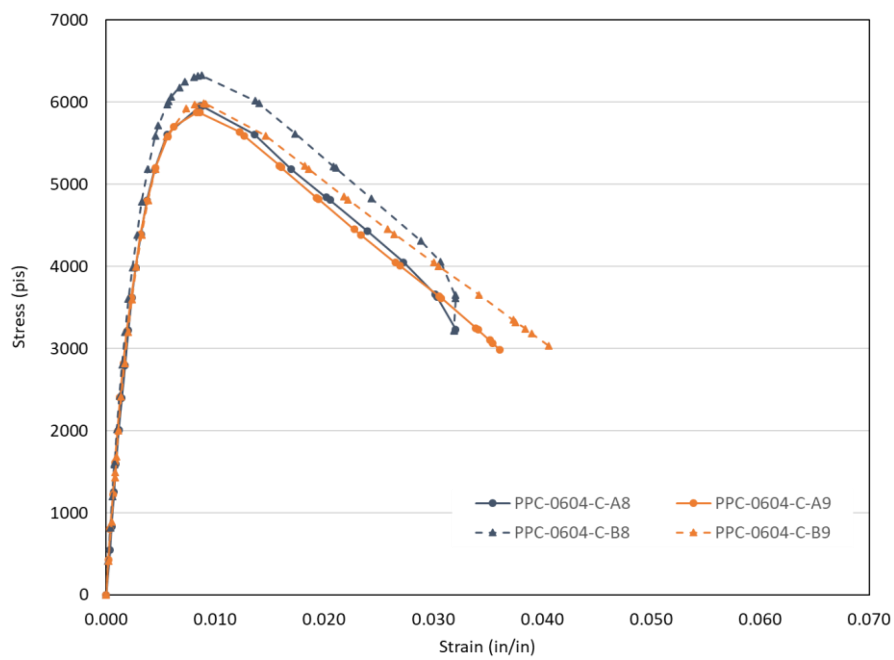


Figure 2-54. Stress-strain of cylinders (28-day)

From the stress-strain curves, the elastic modulus of PPC was evaluated as compiled in Table 2-12. Elastic modulus was evaluated from a trend-line up to around 3,000 psi (about 50% of compressive strength). In addition, the table summarizes the strain at peak stress. Comparison of elastic modulus between 3-day and 7-day shows a minor change, observed in the comparison of compressive strength between 3-day and 7-day. Between 7-day and 28-day, a moderate change occurred in the elastic modulus (149,000 psi increase) despite the similarity of the compressive strengths in the two test ages.

The elastic modulus of PPC is about half of the modulus of non-shrink, cementitious grout materials in Table 2-6. The PPC tested was more deformable, less stiff, and weaker than tested cementitious grout materials in the present research.

Table 2-12. Elastic modulus and strain at the peak stress of PPC

Test Day	Material Properties	PPC-0604A		PPC-0604B		Average
		Specimen2	Specimen3	Specimen2	Specimen3	
3	Elastic Modulus (psi)	1,378,323	1,554,358	2,040,537	1,296,072	1,567,322
	Strain at Peak Stress	0.0079	0.0078	0.0070	0.0095	0.0081
7	Elastic Modulus (psi)	1,888,074	1,373,538	1,928,771	1,296,613	1,621,749
	Strain at Peak Stress	0.0069	0.0102	0.0082	0.0096	0.0087
28	Elastic Modulus (psi)	1,723,078	1,756,506	1,935,730	1,656,924	1,768,060
	Strain at Peak Stress	0.0086	0.0083	0.0088	0.0089	0.0087

CHAPTER 3. INTERPRETATION, APPRAISAL, AND APPLICATIONS

The present research identified potential causes of strength variation and investigated their effects on strength variation in four rounds of compressive strength tests. Table 3-1 shows the evaluation result in which the influence of potential causes is classified into three groups; minor, moderate, and significant. Grout material and mix consistency are two factors that have significant effect on strength variation. In practice, the mix consistency is determined depending on the choice of grout material. Therefore, the two factors can be considered together and are discussed as grout material characteristics in the following. The workmanship and test equipment factors are evaluated to have moderate effect, and these two factors are discussed further.

Table 3-1. Evaluation result of causes of strength variation

Cause	**Effect**		
	Minor	**Moderate**	**Significant**
Grout material			O
Mix consistency			O
Workmanship		O	
Initial curing/storing	O		
Curing method	O		
Test Equipment		O	

3.1 Grout Material Characteristics

The research evaluated that grout material and mix consistency have significant effect on strength variation of cube specimens. Strength test results of cube specimens from the first five batches in Round 3 (Table 2-2) are used as an example. The same UAF researcher who made the cube specimens in Round 1 and Round 2 made the cube specimens for Round 3. Among 39 sets of cube strength test in Round 3, the 8.7% variability limit for three cubes was exceeded in 18 cases (46%), and the 7.6% variability limit for the remaining two cubes was exceeded in 5 cases (13%). In Round 2, the same researcher made cube specimens from one grout material (Sure-Grip®) with two mix consistencies. Test results of those specimens showed that out of 24 cases, there was only 1 case where the 8.7% variability limit was exceeded.

Even an experienced researcher might feel challenged to make cube specimen out of new grout materials. The main difficulty was the workability and consolidation of grout mix. Two grout materials with the same mix consistency can have different workability and working time that relate to consolidation. For example, Sure-Grip® and Sakrete® in flowable consistency were very different in workability. Puddling was enough for consolidating Sure-Grip®, but hand tamping seemed to be more appropriate for Sakerete®. Planigrout and Masterflow® in plastic consistency were also quite different in their workability.

Knowledge and experience of grout materials and mix consistency significantly reduced strength variation. Figure 3-1 shows the compressive strength of Sakrete® (flowable consistency) cubes made by the same UAF researcher for different batches in Round 3 and Round 4. The strength from the first batch exceeded the 8.7% variability limit, but the variation reduced in the following batches as the researcher gained experience of the grout material.

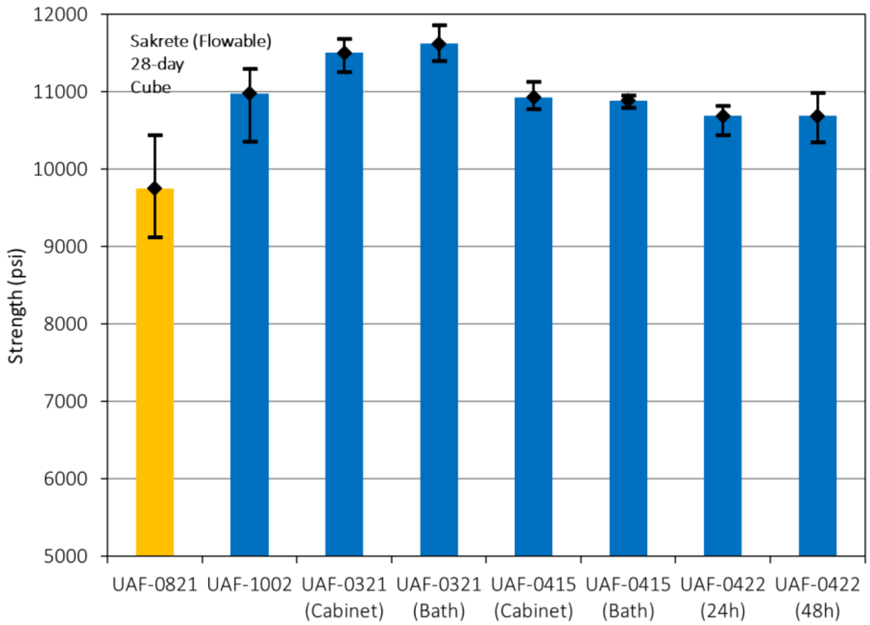


Figure 3-1. Compressive strength of Sakrete® cubes in Round 3 and Round 4

It should be noted that the grout material characteristics factor is different from workmanship. Even in the case of trained technicians, the quality of cube specimens can deteriorate when new grout material is used in molding cube specimens.

3.2 Workmanship and Test Equipment

The research evaluated that workmanship of cube molding and test equipment moderately affect strength variation. The workmanship factor was evaluated from cube specimens made by five DOT&PF–NR technicians and two UAF researchers in Round 1. If a person's workmanship is at low quality as compared with that of other technicians, the strength of the grout can be lower than the design strength, causing a discrepancy problem.

The variation of strength among three cubes is defined as $\left(\dfrac{Max - Min}{Average}\right)$. The variation is used to quantitatively investigate the workmanship factor. Figure 3-2 shows a relationship between the average strength and the variation of 56 sets of specimens (168 cubes) made by UAF Researcher B in Rounds 1 and 2. The sets included strength test results at 1-day, 3-day, 7-day, and 28-day of Sure-Grip® grout material in two mix consistencies. The figure shows the randomly distributed pattern of the variation.

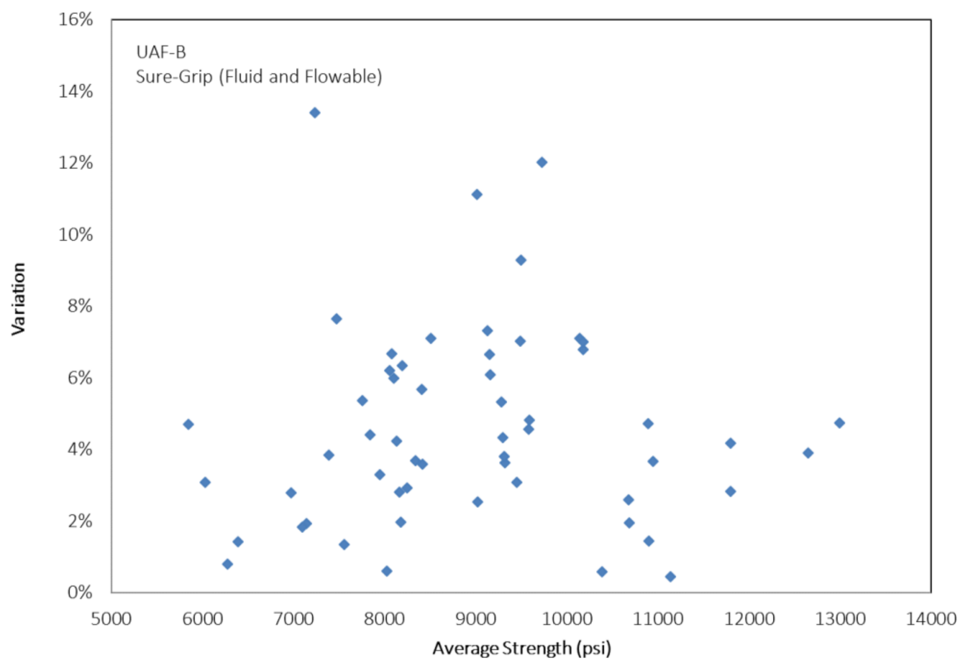


Figure 3-2. Relationship between average strength and variation (Researcher B)

As a random variable, the variation was modeled with a lognormal distribution function. Figure 3-3 shows the cumulative distribution functions of variation built from test results of specimens made by UAF Researcher B. In addition, the function built from the results of specimens made by UAF Researcher A is shown. Table 3-2 indicates the mean and the standard deviation of two curves in Figure 3-3.

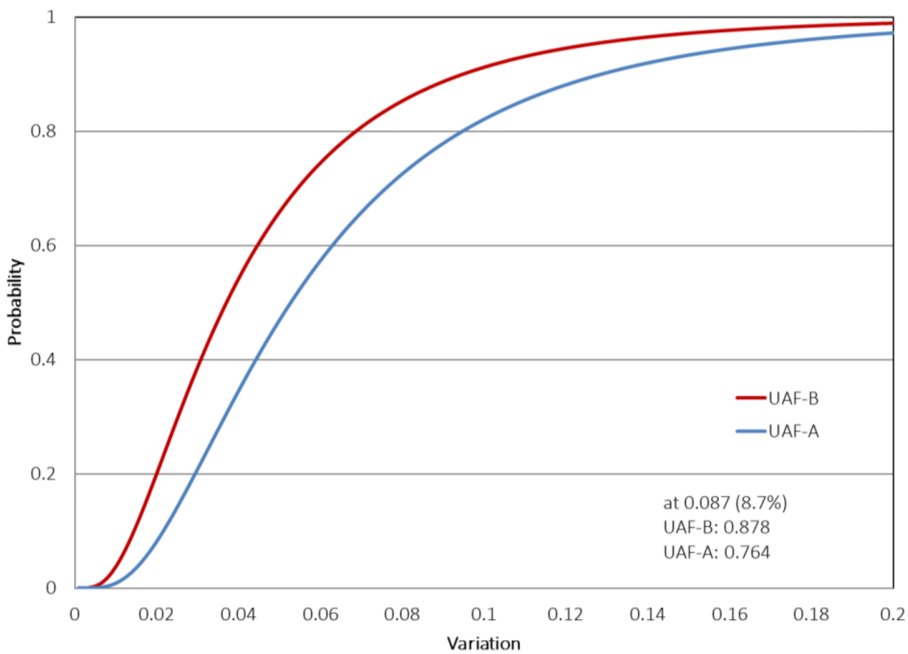


Figure 3-3. Cumulative lognormal distribution of variation

Table 3-2. Lognormal probability models of variation

Data Sets	**mean of** $\ln(X)$	**standard deviation of** $\ln(X)$
UAF-A	-2.942	0.695
UAF-B	-3.295	0.733

If both Researcher A and Researcher B are well-trained to have an equivalent level of workmanship, the test results of their specimens can still have different probability distribution due to the randomness of grout material itself. From the curves in Figure 3-3, it can be seen that the probabilities that the variation is greater than 8.7% are $1-0.878=0.122$ and

$1-0.764=0.236$ for Researcher B and Researcher A, respectively. Between two well-trained people, one of them has about 11% more cases where variation exceeds the 8.7% limit. It should be noted that the variation could easily exceed the variability limits when the workmanship factor combines with the grout characteristics factor.

The test results of specimens made by DOT&PF–NR technicians during the research team's site visits showed that 3 out of 15 cube sets (20%) exceeded the 8.7% variability limit, which was significantly less than previous reported results. The workmanship improved when the specimen molding was more carefully executed with the presence of the research team. There was no case where the variability limit was exceeded among 8 sets of cubes made by the UAF team. However, there is still possibility that strength variation exceeds the variability limit. If it is 12.2% as measured from Researcher B, approximately 1.2 out of 10 cube sets may exceed the variability limit.

Test equipment can induce strength variation. Abnormally reduced 28-day strength for both cube and cylinder specimens from the DOT-0925 batch (Round 3) was likely caused by the test equipment factor. The same machine tested the same grout material several times, and other test results were consistently larger than those from the DOT-0925 batch. The test equipment factor can be eliminated once abnormal test results are observed. Figure 3-4 shows satisfactory and unsatisfactory failure modes of cube specimens in BS EN 12390-3: *Testing hardened concrete (Part 3. Compressive strength of test specimens)* (BS 2002). This figure can be used to identify abnormal test results related to test equipment.

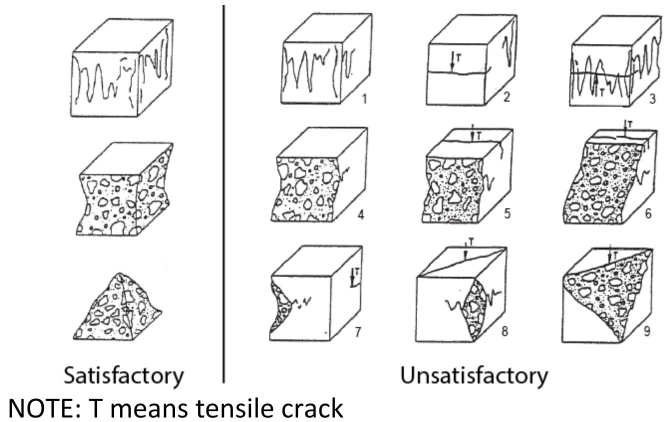


Figure 3-4. Satisfactory and unsatisfactory failures of cube specimens (BS 2002)

3.3 Variability Limits

This section discusses the background of the variability limits, 8.7% and 7.6% in ASTM C109. The research proposes new variability limits based on the data collected in the strength test of grout materials.

Following ASTM E117: *Standard Practice for Use of the Terms Precision and Bias in ASTM Test Methods* (ASTM 2014c), the repeatability limit is the value below which the absolute difference between two individual test results obtained under repeatability conditions may be expected to occur with some probability. If a probability of 0.95 (95%) is used, then the repeatability limit is $2.8 \approx 1.96\sqrt{2}$ times the repeatability standard deviation (ASTM 2014c). Under the repeatability conditions, the same operator using the same equipment within short intervals of time obtains test results with the same method on identical test items in the same laboratory. Similarly, the reproducibility limit is $2.8 \approx 1.96\sqrt{2}$ times the reproducibility standard deviation if a probability of 0.95 (95%) is used. Reproducibility conditions are the conditions where test results are obtained with the same method on identical test items in different laboratories with different operators using different equipment.

In ASTM articles, the variability limits can be recognized from the acceptable range or the permissible range. For example, an acceptable range is found in ASTM C39: *Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens* (ASTM 2018a). As shown in Table 3-3, the acceptable range of individual cylinder specimen varies based on the number of cylinders tested. Besides, the table used the coefficient of variation (cv) instead of mean and standard deviation values. The coefficient of variation is defined as:

$$cv = \frac{S}{\overline{X}} \tag{3-1}$$

where $\overline{X}$ is the mean and S is the standard deviation. It should be noted that the acceptable range of individual cylinder strength is given based on the single-operator cv, which is used for repeatability not for reproducibility (or multi-laboratory cv).

Table 3-3. Precision of test in ASTM C39 (ASTM 2018a)

	Coefficient of Variation[4]	Acceptable Range[4] of Individual Cylinder Strengths	
		2 cylinders	3 cylinders
150 by 300 mm [6 by 12 in.]			
Laboratory conditions	2.4 %	6.6 %	7.8 %
Field conditions	2.9 %	8.0 %	9.5 %
100 by 200 mm [4 by 8 in.]			
Laboratory conditions	3.2 %	9.0 %	10.6 %

[4] These numbers represent respectively the (1s %) and (d2s %) limits as described in Practice C670.

In ASTM C670: *Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials* (ASTM 2015), the 1s% limit is defined as "one sigma limit in percent" and the d2s% limit is the maximum acceptable difference between two test results expressed as a percentage of their average. Therefore, the repeatability limit in ASTM E117 contains the same idea as the acceptable range for 2 cylinders in ASTM C670.

The variability limit values in Table 3-3 were calculated by multiplying cv by the factor that depends on the probability of exceedance. In ASTM C670, a probability of 5% exceedance or a probability of 95% acceptance is generally used, and factors corresponding to 95% was given in Table 3-4. For example, if cv is 3.2%, then the acceptable range (95% acceptance) of test results from 2 cylinder is $3.2\% \times 2.8 = 8.96\%$, which is close to 9.0% in Table 3-3. For 3 cylinders, the acceptable range is $3.2\% \times 3.3 = 10.56\%$.

Table 3-4. Maximum acceptable range of test results (ASTM 2015)

Number of Test Results	Multiplier of Standard Deviation or Coefficient of Varitation[B]
2	2.8
3	3.3
4	3.6
5	3.9
6	4.0
7	4.2
8	4.3
9	4.4
10	4.5

[A] A test result can be a single determination or the average of two or more determinations as defined in the test method.
[B] Values were obtained from Table A7 of "Order Statistics and Their Use in Testing and Estimation," Vol 1, by Leon Harter, Aerospace Research Laboratories, United States Air Force.

Factors in Table 3-4 are set for 5% exceedance or 95% acceptance. For a probability of 1% exceedance or a probability of 99% acceptance, factors in Table 3-5 can be used (Harter 1970). The factors for p = 0.95 in Table 3-5 match with the ones in Table 3-4.

Table 3-5. Multiplication factors for different probability and number of results (Harter 1970)

Number of test results	**Percentage Points of the range**		
	p=0.9500	**p=0.9900**	**p=0.9990**
2	2.771808	3.642773	4.653508
3	3.314493	4.120303	5.063453

In ASTM C109: *Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2-in. or [50-mm] Cube Specimens)*, two different ways are provided to check the acceptable range of test results (ASTM 2016). The acceptable ranges based on the d2s% limits were given in the precision table where different values were provided based on cement types and test age. The maximum permissible ranges between specimens were provided in the *Faulty Specimens and Retests* section. The acceptable ranges were determined based on a probability of 5% exceedance, whereas the maximum permissible range (in the *Faulty Specimens and Retests* section) used a probability of 1% exceedance. In addition, the acceptance ranges are for two specimens, which corresponds to repeatability (the d2s% limits), but the maximum permissible range considers two and three specimens. Table 3-6 shows the difference between two ranges.

In Table 3-6, the acceptable range for 2 specimens is given in the precision table, and the acceptable range for 3 specimens is calculated based on the factor in Table 3-5. The cv in the calculation of the maximum permissible range is 2.1%, which is the within-batch cv. It was noted that 2.1% is an average for laboratories participating in the Portland cement and masonry cement reference sample program of the Cement and Concrete Reference Laboratory (ASTM 2016). The factors for the maximum permissible range are taken from Table 3-5, and calculated maximum permissible range matches with 7.6% and 8.7% in ASTM C109.

Table 3-6. Acceptable range and maximum permissible range in ASTM C109

<table>
<tr><th>Limits</th><th>Number of specimens</th><th>cv (%)</th><th>Factor</th><th>cv×Factor (%)</th><th>Remark</th></tr>
<tr><td rowspan="2">Acceptance Range for Portland Cements</td><td>2</td><td>3.7</td><td>2.771808</td><td>10.25%</td><td>repeatability</td></tr>
<tr><td>3</td><td>3.7</td><td>3.314493</td><td>12.26%</td><td>calculated</td></tr>
<tr><td rowspan="2">Maximum permissible range</td><td>2</td><td>2.1</td><td>3.642773</td><td>7.65%</td><td rowspan="2">1% exceedance</td></tr>
<tr><td>3</td><td>2.1</td><td>4.120303</td><td>8.65%</td></tr>
</table>

NOTE: cv is the coefficient of variation.

For Sure-Grip® and Sakrete® grouts, more cubes were made and tested from Round 1 to Round 4. Table 3-7 summarizes the coefficients of variation for different test age. The cv value at each test age is the average of cv values evaluated at the same test age from Round 1 to Round 4. Finally, the average cv for each grout is calculated from the three test days. Coincidently, the average cv values are the same for these two materials.

Table 3-7. Coefficient of variance of grout materials

Test Day	Sure-Grip® (fluid)		Sakrete® (flowable)	
	cv	Number of Data sets	cv	Number of Data sets
3	0.030	6	0.035	6
7	0.025	7	0.024	6
28	0.026	14	0.022	8
average	0.027		0.027	

NOTE: cv is the coefficient of variation.

Table 3-8 shows the proposed variability limits for grout materials. The same factors in Table 3-6 were used with cv for grout material. In the proposed limits, three cubes satisfy the variability limit if the variation is less than 11.12% of the average. For the remaining two cubes, the variability limit is 9.84% of the average.

Table 3-8. Proposed variation limits for grout materials

Limits	Number of specimens	cv (%)	Factor	cv×Factor (%)	Remark
Maximum permissible range	2	2.7	3.642773	9.84%	1% exceedance
	3	2.7	4.120303	11.12%	

NOTE: cv is the coefficient of variation.

3.4 Grout Cube Making Procedure

ASTM C109 and ASTM C1107 are two ASTM specifications to be used in cube specimen preparation and compressive strength testing. Several parts that need a clarification are described in Table 3-9. In the following section, those issues are discussed based on test results of Sure-Grip® and Sakrete® grouts.

Table 3-9. Comparison between ASTM C109 and ASTM C1107

	ASTM C109	ASTM C1107
Scope	Hydraulic cement mortars	Packaged dry, hydraulic cement grout (non-shrink) intended for use under applied load
Consolidation	Tamp the mortar 32 times in about 10 seconds in 4 rounds (10.4.2)	For fluid or flowable grouts, puddle each with a gloved finger five times to consolidate. Plastic grouts shall be consolidated as described in C109 (11.5.1)

	ASTM C109	ASTM C1107
Mold cover	Not specified	Cover the cube molds with a cover plate (not less than ¼ in.) (11.5.2)
Storage of specimens	Keep all test specimens in the molds in the moist closet or moist room from 24 to 72 h. If the specimens are removed from the molds before 24 h, keep them on the selves of the moist closet or moist room until they are 24-h old, and then immerse the specimens in saturated lime water in storage tanks. (10.5)	Strip molds at 24 ± ½ h after molding or according to manufacturer's instructions. Place specimens in moist cabinet or moist room protected from dripping water. (11.5.3)

Concerning consolidation, it was observed that some grout mixes in flowable consistency might be closer to plastic consistency than fluid consistency. Considering this issue, the research recommends using hand tamping even for grout in flowable consistency. Puddling can be used if hand tamping does not provide any consolidation effect.

After molding, a mold cover should be used to prevent moisture loss from the mold. The molds were completely wrapped with wet cloths and tucked into plastic bags in Round 4. Initial curing of specimens at an elevated temperature (81°F) did not negatively influence the strength gaining of specimens. Demolding at 48 hours after molding did not negatively affect cube strength.

In Round 2, specimens were cured in two conditions, in a moisture cabinet and in a water bath. There was only minor difference in their strength between cubes cured in the two different conditions.

The test results in the present research confirmed that procedures in *ATM 507: Field Sampling and Fabrication of 50mm (2 in.) cube specimens using Grout (Non-Shrink) and or*

Mortar (DOT&PF 2018) are substantially appropriate. As can be seen in Table 3-10, however, ATM 507 avoids using additional tests to classify mix consistency. Consequently, flowable mix consistency was not defined in ATM 507. This approach can induce confusion.

Table 3-10. Grout mix consistency comparison between ATM 507 and ASTM C1107

Consistency	ATM 507	ASTM C1107
Fluid	fluid enough that little or no indentation will be left in the surface after puddling.	Having a time of efflux of 10 to 30 s when tested by the flow cone procedure of Test Method C939
flowable	Not Available	Having a flow of 125 to 145 by the flow test in accordance with the applicable provisions of Test Method C1437; the flow after 5 drops of the flow table in 3 s.
Plastic	viscous enough that an indentation will be left in the surface of the grout after tamping.	Having a flow of 100 to 125 by the flow test in accordance with the applicable provisions of Test Method C1437; the flow after 5 drops of the flow table in 3 s.

The following modifications to ATM 507 are proposed.

- Add NOTE 3 in article 2 in 6. Procedure.

  "NOTE 3: For flowable mixes defined in ASTM C1107, tamp the lift as for plastic mixes. However, puddle the lift as for fluid mixes if tamping does not provide any consolidation."

- Revise article 2 a in 6. Procedure such that

  "For plastic mixes, tamp the lift in four rounds of 8 tamps for a total of 32 tamps with the rubber tamper in **about** 10 seconds."

Actually, it is almost impossible to tamp a lift 32 times (in four rounds of 8 damps) in 10 seconds. "… in about 10 seconds." is the expression in ASTM C1107.

If necessary, paddle mixing can be used to mix grout material in fluid or flowable consistency. The difference in strength was minor. The following procedure is recommended, and the mixing time should be adjusted based on manufacturer's data sheet.

1. Pouring 80-90% of required water in a bucket
2. Pouring all grout material in the bucket
3. Mixing for 2 minutes with a paddle mixer
4. Scraping unresolved grout from the bucket and paddle
5. Mixing for 2 minutes
6. Pouring the remaining water in the bucket
7. Mixing for 1 minute

3.5 Variability Limits of PPC

To measure the compressive strength of PPC, ASTM C579: *Standard Test Methods for Compressive Strength of Chemical-Resistant Mortars, Grout, Monolithic Surfacings, and Polymer Concretes* will be used (ASTM 2018b). Table 3-11 shows the precision table given in ASTM C579. This table was drawn based on a statistical examination of 18 test results from six facilities on a single chemical resistant grout.

When ASTM C579 and ASTM C109 are used for the estimation of PPC compressive strength, knowing an accurate cv is important to determine a correct acceptance range and maximum permissible range. The current values in the two specifications were estimated from the test of quite different materials. ASTM C579 used values for chemical resistant grout, and ASTM C109 used values for Portland cements and masonry cements.

Table 3-11. Compression Method B (psi) (ASTM 2018b)

Material	Average[A] $\bar{X}$	Repeatability Standard Deviation S_r	Reproducibility Standard Deviation S_R	Repeatability Limit r	Reproducibility Limit R
Chemical Resistant Grout	12401	349	1650	978	4620

[A] The average of the laboratories' reported averages.

Based on measured mean and the standard deviation from the present research and other studies, cv values for PPC were evaluated. Table 3-12 summarizes available test results from other studies.

Table 3-12. PPC compressive strength test results from other researches

Lab	Test Day	specimen 1	specimen 2	specimen 3	Mean	cv	Remark
		psi	psi	psi	psi		
MTL	NA	7,142	7,237	7,126	7,168	0.008	2″×2″cube
NCSU	3	5,930	6,840	6,680	6,483	0.075	2″×2″cube
	7	6,980	7,100	7,250	7,110	0.019	
	28	7,020	6,660	7,220	6,967	0.041	
	90	6,730	6,680	5,730	6,380	0.088	
	3	10,580	12,140	9,680	10,800	0.115	2″×2″cube, -4°F
	7	11,830	11,940	12,190	11,987	0.015	
	28	11,200	10,480	10,820	10,833	0.033	
	3	6,200	6,200	6,340	6,247	0.013	ϕ4″×8″ cylinder
	7	6,560	7,030	6,470	6,687	0.045	
	28	5,880	6,450	6,120	6,150	0.047	
	90	6,570	6,420	6,880	6,623	0.035	

Lab	Test Day	specimen 1	specimen 2	specimen 3	Mean	cv	Remark
		psi	psi	psi	psi		
DOT& PF	4h	777	562	833	724	0.198	ϕ4″×8″ cylinder
	17-25.5h	5,027	5,700	5,734	5,487	0.073	
	3	6,012					
	7	5,413					

NOTE: MTL from (MTL 2018); NCSU from (Price, Kowalsky et al. 2018); DOT&PF from (Daugherty 2014).

In Table 3-13, means and cv values for repeatability and reproducibility are summarized. Values for different types of specimens are also separately given. For repeatability, test results from the present research in Table 2-10 were used. For reproducibility, values in Table 2-10 and NCSU test results in Table 3-12 were combined.

Table 3-13. Mean and cv of PPC compressive strength

Type of specimens	Repeatability		Reproducibility	
	mean (psi)	cv	mean (psi)	cv
2″×2″ cube	6,251	0.020	6,451	0.028
ϕ4″×8″ cylinder	5,897	0.022	6,051	0.026

NOTE: cv is the coefficient of variation.

The acceptable range of individual specimen strengths in Table 3-14 were calculated based on the cv values of PPC in Table 3-13 following the format in ASTM C39 (Table 3-3). The cv for repeatability was used in the calculation.

In the format in ASTM C579 (Table 3-11), both repeatability and reproducibility were used as in Table 3-15. In the table, averages were from the reproducibility in Table 3-13. Both

Table 3-14 and Table 3-15 were based on the 95% acceptance level, and factors in Table 3-4 were used.

Table 3-14. Strength variability limits of PPC in ASTM C39 format

Type of specimens	**cv (%)**	**Acceptable range of individual specimen strengths (95% acceptance)**	
		2 specimens	**3 specimens**
2″×2″ cube	2.0	$2.0 \times 2.8 = 5.60\%$	$2.0 \times 3.3 = 6.60\%$
ϕ4″×8″ cylinder	2.2	$2.2 \times 2.8 = 6.16\%$	$2.2 \times 3.3 = 7.26\%$

NOTE: cv is the coefficient of variation.

Table 3-15. Strength variability limits of PPC in ASTM C579 format (psi)

Type of specimens	**Average**	**Repeatability standard deviation**	**Reproducibility standard deviation**	**Repeatability Limit**	**Reproducibility Limit**
2″×2″ cube	6,451	127	182	357	509
ϕ4″×8″ cylinder	6,051	132	159	370	445

The material properties of PPC are significantly different from conventional cementitious grout materials. The compressive strength of PPC may not be a primary property for a proper understanding of the material. As another important material property, the elastic modulus of PPC was compared with Sure-Grip® and Sakrete® grouts in Table 3-16.

Table 3-16. Comparison of elastic modulus and cube strength at 28-day

Material		**Elastic Modulus**	**Cube Strength**
Non-Shrink Cementitious Grout	Sure-Grip®	4,320 ksi[1]	10,807 psi
	Sakrete®	3,752 ksi[1]	10,935 psi
PPC		1,768 ksi[2]	6,562 psi

NOTE: 1. Measured from ϕ6″×12″ cylinder; 2. Measured from ϕ4″×8″ cylinder.

To compare PPC with cementitious grout, Figure 3-5 shows the schematic stress-strain curves of both materials. For Sure-Grip®, it was assumed that strain at the peak stress was 0.2%. For PPC, measured strain values were used in the figure. The main benefit of PPC material is its deformability before and after the peak stress.

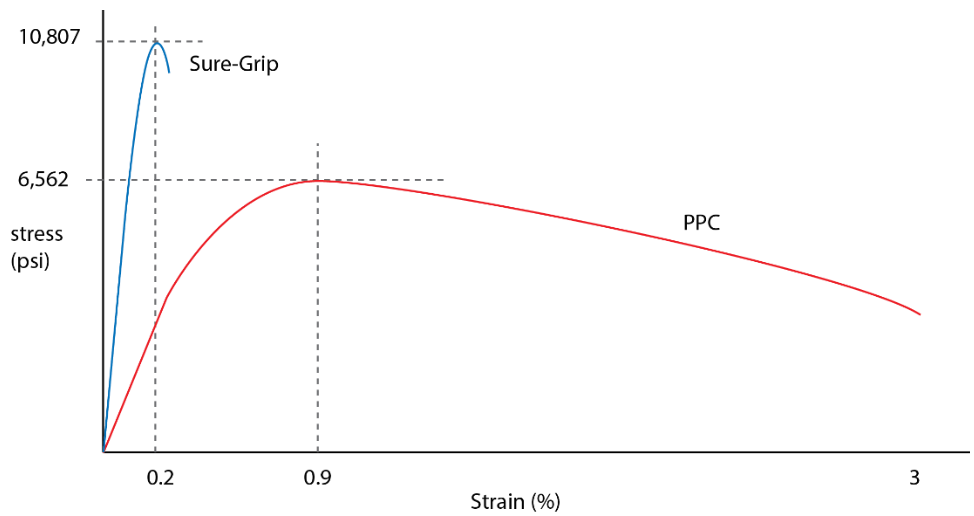


Figure 3-5. Schematic stress-strain relationships of PPC and Sure-Grip® grout

CHAPTER 4. CONCLUSIONS AND SUGGESTED RESEARCH

4.1 Conclusions

The present research identified six factors – grout material, mix consistency, workmanship, initial curing/storing, curing method, and test equipment – as causes of compressive strength variation. Their effects on strength variation were investigated by testing compressive strength of cube specimens made by DOT&PF–NR technicians and UAF researchers from 5 grout materials used or considered to be used in DOT&PF projects. $\phi 4'' \times 8''$ cylinders were also tested to investigate relationship between cube strength and cylinder strength. The elastic modulus of grout materials was measured from $\phi 6'' \times 12''$ cylinders.

In addition, the research selected Polyester Polymer Concrete (PPC) as a grout material, and some mechanical characteristics were tested. The compressive strength of PPC is less than the requirement for non-shrink, cementitious grout materials in *DOT&PF Standard Specifications for Highway Construction*. However, PPC has greater deformability than cementitious grout materials and is able to deform significantly before and after it reaches the peak stress.

The following are the conclusions of research:

- Grout material characteristics such as grout material and mix consistency have significant effect on strength variation. Workability and consolidation can be different from one material to another. Consequently, they affect the strength and strength variation. Even for a well-trained technician, grout material characteristics can cause difficulty as a factor to induce strength variation.

- Workmanship and test equipment were evaluated to have moderate effect on strength variation. Especially, strength variation can increase when the workmanship factor combines with the grout material characteristics factor. The test equipment factor can generate inconsistent test results compared to the previous results of the same grout material.
- Initial curing/storing of cube specimens and curing method have only a minor effect on strength variation.
- Elastic moduli of four grout materials were measured. They varied from 3,285 ksi – 4,457 ksi at 7-day, and the range was 3,752 ksi – 4,557 ksi at 28-day.
- The compressive strengths of cube and ϕ4″×8″ cylinder specimens were compared. The cylinder strength was 77% – 86% of cube strength.
- For Sure-Grip®, the probability of having a variation greater than 8.7% among three cubes was 0.122 based on a lognormal probability distribution.
- The mean and the standard deviation for Sure-Grip® and Sakrete® were estimated. For both materials, the coefficient of variation was 2.7%. Statistical evaluation based on a coefficient of variation of 2.7% showed that the variability limit of three cubes can be 11.12% (from 8.7%), and the variability limit of two cubes can be 9.84% (from 7.6%).
- The present research showed that ATM 507 procedures were appropriate in molding cube specimens from grout materials. Two modifications to ATM 507 were proposed. For flowable mix consistency, the research recommend hand tamping as a primary consolidation method over puddling.

- The compressive strength of PPC was less than non-shrink, cementitious grout materials. The mean and standard deviation of strengths were calculated, and strength variability limits for PPC were provided.
- The elastic modulus of PPC was 1,768 ksi at 28-day, less than half of elastic modulus of conventional cementitious grout materials. The strain at the peak stress was much larger than cementitious grouts. PPC substantially deformed before and after the peak stress.

Among identified causes of strength variation, grout material characteristics and workmanship are the ones that need subsequent improvement. Activities to alleviate effects on strength variation from them include:

- Enhancing the understanding of grout materials by conducting practice mixing or test mixing before grouting operation at construction sites. Communication with manufacturers and contractors are encouraged to estimate the feasibility of grouting operation planned at the site.
- Regular hands-on training to improve and enhance cube-making workmanship is advised. Regular skill training for initial curing/storing, transporting, and testing cube specimens should be provided.

4.2 Suggested Research

The DOT&PF adopted the performance requirements in ASTM C1107 for its grout specifications as well as increasing the 28-day strength to 9,000 psi. Not only the 28-day strength requirement but also the earlier age strength requirements should be added to DOT&PF specifications, since strength requirement at early test age in ASTM C1107 is not for high-strength grout materials. Moreover, DOT&PF may revise the performance requirement for dimensional stability. Varga and Graybeal (2015) argued that the performance requirement in ASTM C1107 is not sufficient to provide a proper level of dimensional stability.

Various new construction materials become available in the market every year. Research on the new materials suitable for grouting keyway joints of DBT girders is necessary. For example, the PPC tested in the present research is a flexible material that allows large deformation between the two adjacent girders connected by grout. For new materials, various mechanical properties should be identified for the design and construction of keyway grout. Required mechanical properties include compressive strength, tensile strength, shear strength, bond strength, constructability, and durability.

The performance of grout will be better understood from numerical and experimental research on the system including keyway joints, bridge deck, and grout. Numerical analysis such as finite element analysis is an effective method to investigate stress distribution and deformation that can occur in the grout, concrete, and interface between the two. It is also possible to study inelastic behavior of the joint system once mechanical property models are well developed.

Loading tests on large-scale specimens for their serviceability and strength will provide reliable information about the performance of grout and keyway joint system. Since the keyway joint performance depends on various factors such as grout material, interface properties, concrete material, location and amount of loading, and supporting condition, loading tests will be the best way to investigate the combined effect of those factors.

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Appendix A. Literature Review

Concerning the performance of grout materials, Gulyas et al. (1995) utilized composite tests (sub-assemblage test) of grouted keyway specimens and compared non-shrink grouts and magnesium ammonium phosphate (MAP) mortars. The MAP material performed better than non-shrink grout in many aspects. Based on component and composite tests, it was concluded that the use of non-shrink grout (Set non-shrink grout) should be discouraged due to the lack of performance compared with MAP type grout (Set-45 HW grout). The inadequacies of using non-shrink grout in shear keyways were also discussed in Gulyas and Champa (1997). Issa (2002) found that composite testing of keyway assemblies which have been grouted was a more appropriate testing method when translating results to the field than component material property test. This kind of testing relies less on the component material properties as it does on the bond strength of grout material to girders as well as the shrinkage limits of the grouting materials. Comparison between standard non-shrink grout and Set-45 HW indicated that bond failure occurred in the non-shrink grout while base concrete failure occurred in the Set-45 HW mortar.

Issa et al. (2003) tested Set-45, Set-45 HW, Set grout, and a polymer concrete mix for direct tension, direct shear, and flexural strength. BASF Set-45 and Set-45 HW are MAP materials. The polymer concrete (Emaco 2020 Regular) mix outperformed all other materials in all tests, by about 20 to 30 percent over Set grout in flexural test and direct tensile and nearly 90 percent in direct shear. Set grout had the second highest performance in all categories, about 10 percent over either Set-45 or Set-45 HW which had similar results in direct shear and tension. Chloride permeability was also tested, where the polymer concrete was found to be least permeable while Set grout was over 4 times more permeable than Set-45 due to its high water content. The Set grout specimens also showed large shrinkage, while the polymer concrete exhibited the least. While the polymer concrete is more expensive to produce, its performance was better in nearly every category. Set grout mix was the second best in most categories and was more practical in terms of price to be used in most joints. Oesterle et al. (2009) used Set-45 HW and EUCO-SPEED MP for grout in the NCHRP 12-69 study during the investigation of precast deck panel connections. The design strength of both grout materials was 7000 psi.

The performance of grout material used in various bridge applications, specifically in Accelerated Bridge Construction practices, has been notified that there is not a general consensus on the best type of material to be used (Swenty and Graybeal 2013). Also, no prior study has completed a comprehensive assessment of candidate field-cast grout-type materials covering the wide range of relevant materials and characteristics. Among 9 different types of grout materials, three conventional pre-bagged cementitious materials were selected. They were Five Star Grout, BASF Embeco 885, and Harris Construction Grout. The 28-day compressive strength of these grout materials was in a range of 6700 – 8940 psi as it was measured based on ASTM C109 with 2 in. × 2 in. cube specimens. It was observed that the bond strength of these grout materials to the precast concrete was approximately half the tensile strength of grout materials, which implied the difficulty of making so-called CIP-emulative connection with these materials.

Ozyildirim and Moruza (2015) compared the performance of three different grouting materials: non-shrink grout, High-Performance Fiber-Reinforced Concrete (UHPC) with steel fiber, and Engineered Cementitious Composite (ECC). These materials were used in two bridge projects where adjacent concrete box girders were employed. Using fiber in grout materials resulted in many tight micro-cracks (0.1 mm or smaller) rather than larger collected cracks. The micro-cracks reduced penetration of moist, including inhibiting the intrusion of corrosive chemicals and chlorides. The use of shrink reducing admixtures also greatly affected the formation of cracks due to long term exposure to environmental conditions in low paste content mixes. Both UHPC and ECC are self-consolidating materials and require no vibration. The 28-day strength of used ECC and UHPC was 8255 psi and 23345 psi, respectively.

In a recent study, the performance of different products of rapid-hardening, pre-packaged repair materials, such as rapid-set, cement-based, and resin-based mortars or concretes was compared (Yang et al. 2016). The compressive strength was tested with 4 in. × 8 in. cylindrical specimens made from plastic molds, and Figure A-1 shows the test results. The control specimens were made of Type III Portland cement-based concrete.

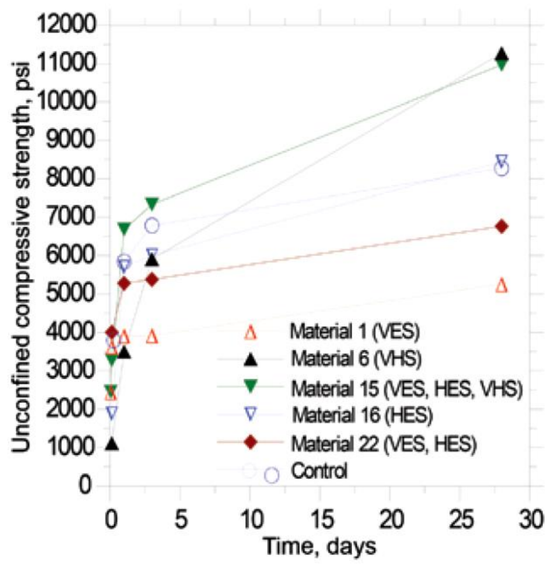


Figure A-1. Compressive strength test results (HES: High Early Strength; VES: Very Early Strength; VHS: Very High Strength) (Yang et al. 2016)

Material 6 in Figure A-1 was referred to as “high-early-strength cementitious mortar with extended working time” and Material 15 was “rapid-set low-shrinkage high-early-strength mortar.” In the study, grout materials that can develop a compressive strength of 10 ksi or higher within 28 days were classified as VHS (Very High Strength). It was noted that VHS was not favorable for most applications since its potential to develop shrinkage cracking was high. It was concluded that the lack of freezing and thawing resistance and the high risk of shrinkage cracking are likely to cause premature failure when grout materials are exposed to severe environments.

Cube specimens (2 in. × 2 in.) are used in compressive strength test in China, Great Britain, Germany, and many other countries in Europe. As stated in current DOT&PF’s Standard Specifications for Highway Construction (DOT&PF 2017), cube tests in AASHTO T106 (AASHTO 2015) or ASTM C109 (ASTM 2016) are used to test grouting materials meeting ASTM C1107 (ASTM 2014b). However, difference in compressive strength test results between cube specimens and cylindrical specimens has been known.

Studies by Graybeal and Davis (2008) and Elwell and Fu (1995) indicated that a 2 in. cube specimen may not be a suitable substitute for the standard 4 in. -diameter cylindrical specimen. Cube specimens consistently resulted in higher compressive strengths, which may be misleading when using grout material in the field. Theoretically, the cause of this is due to the likelihood having an inconsistency in mix or anomaly in a larger specimen which would lower the overall strength of the specimen. According to Graybeal and Davis (2008), the use of cube specimens became increasingly popular because cube specimens require less force to break and surface preparation for test was easier. Figure A-2 shows the compressive strengths of different sizes of specimens of different types of UHPC tested in (Graybeal and Davis 2008).

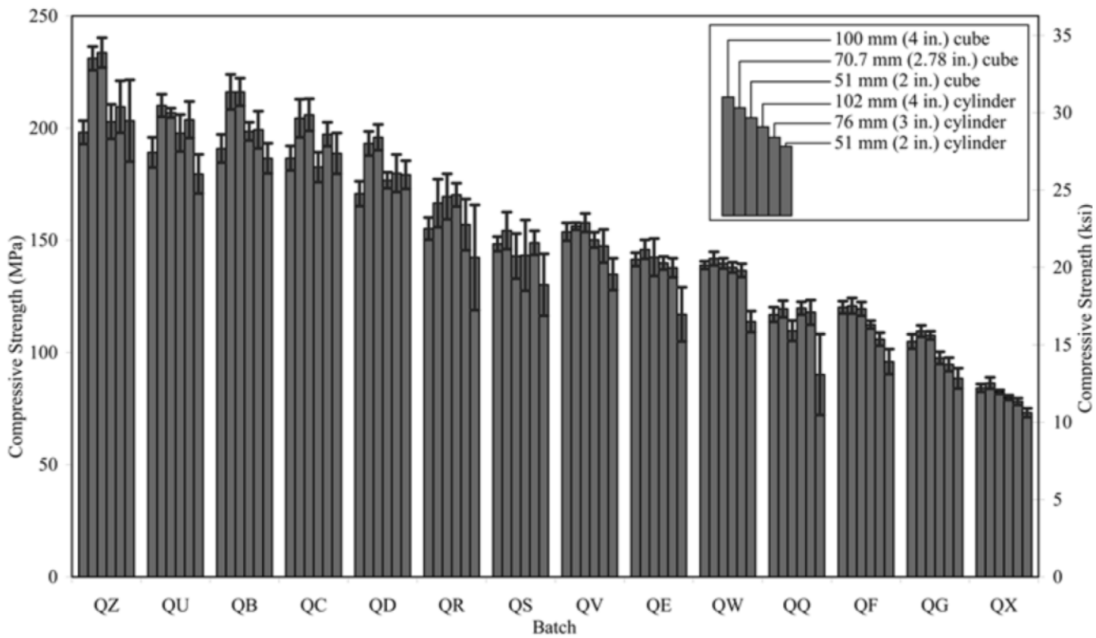


Figure A-2. Compressive strength of cylinder and cube specimens (Graybeal and Davis 2008)

The 4 in. cube, 4 in. cylinder, and 3 in. cylinder specimens were acceptable and interchangeable for the determination of compressive strength of UHPC, while the 2.78 in. cube was only acceptable when the capacity of testing machinery was a concern and a factor of 0.96 may be applied to results in order to convert cube strength to equivalent 3 in. cylinder results. It was mentioned that 2 in. cube and 2 in. cylinder should not be used because they have shown very high variability with little correlation to the 3 in. and 4 in. cylinder results. Elwell and Fu (1995) agreed that cube specimens exhibited higher variability due to their smaller size, however they added that the cube specimens were more sensitive to aggregate grading due to the relative size of aggregate particles to the dimensions of the specimen. Gulyas et al. (1995) proposed to use a factor of 0.75 – 0.80 to convert cube strength to cylinder strength (4 in. diameter).

The variability of compressive strength test results has been reported in some studies. The strength could not reach to the value specified by manufacturer or the variability of test results was significant although the 28-day strength of non-shrink cementitious grout was less than 9000 psi in most of previous studies. De Murphy et al. (2010) studied design and construction practices to reduce cracking in the shear keys of

Pennsylvania Department of Transportation (PennDOT) precast box beam bridges. In the research, fiber-reinforced cementitious grout and epoxy grout were used in shear keys. The compressive strength test results of cementitious grout (Five Star Grout) showed much less strength than the manufacturer's as shown in Table A-1.

Table A-1. Compressive Strength Test Results of Cementitious Grout (De Murphy et al. 2010)

Curing Day	*Manufacturer's (psi)*	*First Batch (psi)*	*Second Batch (psi)*
3	3500	1500	1462
7	5000	1880	1575
28	6500	1881	1705

Specimens from the two batches did not reach the strength provided in the manufacturer's specifications. Compressive test results of another cementitious grout (BASF Masterflow 713) also showed less 28-day strength than manufacturer's. Cylindrical specimens with 2 in. diameter and 4 in height were used in the strength test and an average value was taken from 6 specimens.

For non-shrink grout, Ohio Department of Transportation (ODOT) specification requires that three 3in. × 6 in. cylinders be tested. The minimum required compressive strength of the cylinders is 5,000 psi (ODOT). In a test program, two commercial grout materials were used. They were Conset made by Chemmasters and CG-86 made by W. R. Meadows. The compressive strength of two types of specimens, 3in. × 6 in. cylinders and 2in. ×2in. cubes, were compared as shown in Table A-2.

Table A-2. Compressive Strength Test Results of CG-86 Grout in ODOT (ODOT) (unit: psi)

	Specimens	*1*	*2*	*3*	*4*	*5*	*6*	*Average*	*Variation*
3day	Cylinders 3in. × 6 in.	6,840	7,170	6,320	6,500	7,360	7,170	6,893	1,040 (15%)
	Cubes 2in. ×2in.	6,200	6,480	6,370	6,640	6,340	6,040	6,345	600 (9%)
7day	Cylinders 3in. × 6 in.	6,930	6,800	6,080	6,830	7,150	6,990	6,797	1,070 (16%)
	Cubes 2in. ×2in.	7,150	6,490	6,160	6,690	6,360	6,740	6,598	990 (15%)
28day	Cylinders 3in. × 6 in.	10,150	8,090	9,680	9,160	10,030	8,680	9,298	2,060 (22%)
	Cubes 2in. ×2in.	10,120	8,460	7,560	9,220	9,980	8,970	9,052	2,560 (28%)

There were differences in compressive strength between 3in. × 6 in. cylinders and 2in. ×2in. cubes at each test day. The last column is added to show the maximum variation among 6 specimens and the percentage to the average value. The variations were small at early days, but they became large at 28 days. In ASTM C 109, the maximum variation should be less than 8.7% when three specimens are tested. Although the average was taken from six specimens, 22 – 28% variations were rather large.

In an experimental study of precast deck panel connections, Porter (2009) used Masterflow 928 non-shrink grout in the connections. Two cylindrical specimens were generally used to test the compressive strength, and parts of test results are summarized in Table A-3. It seems that ASTM C109 was not used since cylindrical specimens were used, but the two sets of test results did not satisfy the variability limit of 7.6%.

Table A-3. Grout Compressive Strength (Porter 2009)

Batch	*Cylinder #*	*1-day f_c' (psi)*	*3-day f_c' (psi)*
1	*1*	4169	NA
	2	3854	NA
2	*3*	NA	6659
	4	NA	6111

Recently, the dimensional stability of various grout materials was studied in (Varga and Graybeal 2016). Three different types of non-metallic, cement-based grout materials were used with 8 other grout materials. For compressive strength test of grout materials, 2 in. × 2in. cube specimens were used. The cube specimens were cured in molds for 24 hours, then, they were demolded and sealed in plastic bags until the age of testing. Table A-4 shows the compressive strength test results of materials. Grout types G1, G3, and G4 were non-metallic, cement-based materials. Only G3 reached to a 28-day strength greater than 9000 psi. The standard deviation of the strength was 290 psi.

Table A-4. Compressive Strength Results of Grout Materials (Varga and Graybeal 2016)

Grout	**Average Compressive Strength, psi**					
	4 h	**8 h**	**1 d**	**3 d**	**7 d**	**28 d**
G1 - 0.18	[a]	[a]	3,713 (62)[b]	5961 (128)	6,541 (141)	7,281 (335)
G2 - 0.17	[a]	[a]	5,018 (109)	7,150 (222)	8,833 (15)	9,805 (219)
G3 - 0.16	[a]	[a]	4,424 (120)	7,092 (321)	7,600 (170)	9,805 (290)
G4 - 0.17	[a]	[a]	2,408 (75)	3,800 (110)	5,149 (25)	6,338 (60)

DOT&PF adopted the performance requirements in ASTM C1107 (Table A-5) in its grout specifications except increasing the 28-day strength to 9000 psi. Gulyas et al. (1995) pointed out that the specification in ASTM C1107 should include additional three properties: maximum allowable shrinkage, minimum bond strength; and the requirement for minimum strength of 6000 psi. Since the strength of typical precast concrete members was 6000 psi, the minimum strength of grout was expected to be at least equal to the strength of connecting concrete members.

The interface between existing concrete surface and grout tends to crack first in many applications (Issa et al. 1995). For crack control, therefore, the bond strength is a controlling factor than cracking strength of adjoining materials (Swenty and Graybeal 2013). Previous research indicated that ASTM C496: Splitting Tensile Strength of Cylindrical Concrete Specimens can provide reasonable results for bond strength (Geissert et al. 1999). To test bond strength between the precast concrete and grout, Graybeal (2017) proposed four methods following existing ASTM specifications and convenience for implementation.

They are (1) flexural beam test, (2) splitting cylinder test, (3) slant-shear compression test, and (4) direct tension pull-off test.

Table A-5. Performance Requirement in ASTM C1107

Property	*Requirement*	*Related Articles*
Compressive strength	1-day 1000psi 3-day 2500psi 7-day 3500psi 28-day 5000psi	ASTM C109
Consistency	Plastic, flowable, fluid	ASTM C125, ASTM C1437, ASTM C939, ASTM C827
Early height change	+4.0%	ASTM C827
Height change of moist cured grout	1-day 0.0 to +0.3% 3-day 0.0 to +0.3% 7-day 0.0 to +0.3% 28-day 0.0 to +0.3%	ASTM C1090, ASTM C157

In a full-scale precast deck panel test, it was also observed that non-shrink cementitious grout joining deck panels typically exhibited shrinkage cracks in connection region (Haber and Graybeal 2015). These shrinkage cracks eventually propagated during cyclic loading. Improved connecting surface prepared by pressure wash or sand blast did not improve the bond strength between the existing concrete and grout material. It was observed that most cement-based grout materials that performed well for dimensional stability (shrinkage) in accordance with ASTM 1107 may result in a lack of dimensional stability. Separate testing to evaluate autogenous and drying shrinkage (and expansion) showed that expansion might occur during the first day or two, followed by shrinkage, especially in drying conditions (Varga and Graybeal 2015).

When comparing the performance of gout materials, it was pointed out that limited research had been conducted to provide a consistent comparison among a large number of different types of materials. Also the importance of developing adequate performance-based criteria to ensure appropriate selection of grout materials was emphasized (French et al. 2011). As performance criteria for selecting durable closure pour material, Table A-6 was proposed. In the study, four overnight cure grout materials and four special concrete mixes (7-day cure) were selected for material property tests. Among four overnight cure grouts, Five Star Patch was cement-based, while EUCO-SPEED MP, Set-45 and Set-45 HW were all pre-packaged MAP type. The grout property tests were more extensive for MAP type than cement-based type in this study and the proposed performance criteria were not necessarily for cement-based materials.

Table A-6. Proposed Performance Criteria of Closure Pour Materials (French et al. 2011)

<table>
<tr><th>Performance Characteristic</th><th>Test Method</th><th colspan="3">Performance Criteria</th></tr>
<tr><td>Compressive Strength (CS), ksi</td><td>ASTM C39 modified</td><td colspan="3">6.0≤CS
@ 8 hours (overnight cure)
@ 7 days (7-day cure)</td></tr>
<tr><td>Shrinkage[a](S),
(Crack age, days)</td><td>AASHTO PP34 modified</td><td colspan="3">20<S</td></tr>
<tr><td>Bond Strength (BS), psi</td><td>ASTM C882 modified</td><td colspan="3">300<BS</td></tr>
<tr><td>Chloride Penetration[b](ChP),
(Depth for Percent Chloride of 0.2% by mass of cement after 90-day ponding, in)</td><td>ASTM C1543 modified</td><td colspan="3">ChP<1.5</td></tr>
<tr><td rowspan="2">Freezing-and-thawing Durability (F/T), (relative modulus after 300 cycles)</td><td rowspan="2">ASTM C666
Procedure A modified</td><td>Grade[c] 1</td><td>Grade 2</td><td>Grade 3</td></tr>
<tr><td>70%≤F/T</td><td>80%≤F/T</td><td>90%≤F/T</td></tr>
</table>

a: No S criterion need to specified if the Closure Pour material is not exposed to moisture, chloride salts or soluble sulfate environments.

b: No ChP criterion need to specified if the Closure Pour material is not exposed to chloride salts or soluble sulfate environments.

c: Grades are defined as follows

<table>
<tr><td rowspan="4">Freezing-and-thawing Durability (F/T)</td><td rowspan="4">Is the concrete exposed to freezing-and-thawing environments?</td><td rowspan="3">Yes</td><td rowspan="3">Is the member exposed to deicing salts?</td><td rowspan="2">Yes</td><td rowspan="2">Will the member be saturated during freezing?</td><td>Yes.
Specify F/T-Grade 3</td></tr>
<tr><td>No.
Specify F/T-Grade 2</td></tr>
<tr><td colspan="3">No. Specify F/T- Grade 1</td></tr>
<tr><td colspan="5">No. F/T grade should not be specified.</td></tr>
</table>

Matsumoto et al. (2001) studied precast bent cap system and proposed performance criteria for grout used in the precast bent cap system. Table A-7 shows selected properties from the proposed criteria. The compressive strength of grout should be greater than the specified 28-day concrete compressive strength by a minimum of 1000 psi. Also, a factor of 1.25 was used to convert cylinder strength to cube strength. A margin of 1000 psi accounts for the likelihood that the actual concrete strength will exceed the specified strength as well as the possibility of low grout strength.

Scholz et al. (2007) studied connections between girders and full-depth precast deck panels. In the connection, four grout materials were tested: ThoRoc 10-60 Rapid Mortar, SikaQuick 2500, Five Star Highway Patch, and Set-45 HW. ThoRoc 10-60, SikaQuick 2500, and Five Star Patch were all cement-based, while Set-45 HW was MAP type. The 7-day compressive strength of these grouts was in a range of 4710 psi – 6380 psi. The research also showed that no significant increases in strength at the interface by exposing the aggregate on the bottom slab surface. Based on test results, an exposed aggregate surface on the bottom of the slab did not provide a sufficient increase in horizontal shear resistance to justify the additional cost of exposing the aggregate. The research proposed performance specification for grouts used in full-depth precast concrete bridge deck panel systems as summarized in Table A-8. Neat grouts as well as extended grouts were allowed to be used. For extended Grouts, 3/8 in. pea gravel aggregate extension may be used, but the extension shall not exceed 50% by weight.

Table A-7. Compressive Strength Performance Criteria of Precast Bent Cap Grout (Matsumoto et al. 2001)

Property	*Performance Criteria*	*Remark*
Compressive strength	1 day: 2500psi 3 days: 4000psi 7 days: 5000psi 28 days: max[5800psi, $1.25\left(f'_{c,CAP}+1000\right)$	ASTM C 109
Flowability	fluid consistency efflux time: 20-30 seconds	ASTM C 939
Set Time	Initial: 3 – 5 hrs Final: 5 – 8hrs	ASTM C 191

Table A-8. Performance Specification for Grouts used in Full-Depth Precast Concrete Bridge Deck Panel (Scholz et al. 2007)

Property	*Performance Criteria*	*Remark*
Compressive Strength	1 hour: No strength 2 hour: Determined by engineer-of-record based on construction procedure. 1 day: Minimum 4000 psi 7 day: Minimum 5000 psi 28 day: Minimum 6000 psi	ASTM C 109
Splitting Tensile Strength	1 day: Minimum 200 psi 7 day: Minimum 400 psi 28 day: Minimum 600 psi	ASTM C 496
Shrinkage	28 day: Maximum 0.04% (400 microstrain)	ASTM C 157 ASTM C 596
Sulfate Resistance	28 week: 0.10% (1000 microstrain)	ASTM C 1012
Freeze-Thaw Resistance	300 Cycles: Minimum 80% Durability Factor	ASTM C 666, Procedure A
Scaling Resistance	25 Cycles: 0 Scaling Rating (no scaling)	ASTM C 672

Although it is understood that the moisture content in the concrete substrate affects bond strength between the concrete and grout, there is no test method for determining the optimum concrete substrate moisture condition for a given grout type or a specification that can be used in the field (Graybeal 2017). In order to provide the so-called saturated surface dry (SSD) moisture condition at the connecting surface, it was tested that the burlap approach was effective (Graybeal 2017). In addition, the connecting concrete surfaces should be prepared by removing grit and/or loose particles prior to placement of connections grouts. It was also noted that thermal expansions and contractions due to environmental changes might affect the bond between the grout and the concrete. In this case, compatibility of thermal expansion/contraction between the grout and the substrate will be required.

To ensure contractors' capability of grouting jobs, in some cases, contractors need to demonstrate proper grouting skill with a full-scale wood mock-up (Culmo 2011). Once the grout is cured, the mock-up is dissembled and the gout is inspected. For training field inspectors, it was recommended bringing manufacturer technician to the site for training inspection staff on proper installation techniques.

In one of manufacturer's handbook, some construction related issues are summarized (Five Star Products INC. 2007). Concerning the consistency, it is important to have information on grout consistency not just after mixing (initial test value) but after a specified period of time (delayed test value) since grouts rarely are placed completely and immediately after mixing on job sites. For mixing cementitious grout, a mortar mixer with moving blades to mix grout is recommended. The mixing should start with the minimum amount of potable water printed on the manufacturer's bag or label. Run the mixer until the surface water has disappeared and a uniform consistency is reached. Only then, add the least amount of additional potable water needed to obtain the desired consistency, and remix. If at all possible, cement-based grouts should not be placed in lifts or layers.

The grout consistency depends on the amount of water used for mixing, and the amount usually applies only under certain temperature conditions. It was noted that ice or warm water may be used to adjust the flow and that contractors need to mix trial batches of grout for specific field conditions and to use a flow cone (Matsumoto et al. 2001). It was recommended that two flow cone tests be conducted: one immediately after mixing and a second at the expected pot life of the grout. The second test is intended to confirm that a batch of grout will maintain a suitable flowability throughout grouting operations. In addition, the working time, or pot life, of the grout should be a crucial factor in grout selection (Matsumoto et al. 2001). It is important to notice that the estimate of the total grouting time account for: 1) conducting the flow cone test, 2) transferring grout from the mixer to dispensers, 3) transporting grout to point of placement, and 4) grouting one or more connections.

In the literature review, it was known that there are not enough information about non-shrink, non-corrosive, non-metallic, cementitious grouts of which 28-day compressive strength is 9000 psi or above. Most of early studies about non-shrink grouts used materials of which strength was around 6000 psi. Specifically, non-shrink cementitious grouts having a 28-day strength of 9000 psi or above for fluid mix are not well studied. Advantages or disadvantages of non-shrink grout materials reported in early studies should be revisited based on material property tests of these new high strength grout materials.

One of the examples where significant variability of compressive strength test results was observed is the Tulsona bridge project. The grout used in the project was Sakrete Non-Shrink Construction Grout. The 28-day compressive strength of this grout is 9000 psi for plastic mix and 8000 psi for flowable mix. The specifications provided by manufacturer can be found in Appendix F of this report. The strength test result of cube specimens did not satisfy the variability requirement in ASTM C1107. The result from 4 in. × 8 in. cylinders satisfied the variability requirement and the average strength was 7813 psi. If a conversion factor of 1.25 is used to estimate the strength for cube specimens, the strength would be 9750 psi, which satisfies the specifications and the DOT&PF requirement. However, the used conversion factor may be different for this grout. Comparative studies are required to evaluate a correct conversion factor.

Concerning the variability of compressive strength, test results from other studies show some cases where significant variability was experienced. In such cases, the significant variability occurred in cube specimens and cylindrical specimens made from various non-shrink grout materials. In other cases, test results showed that the strength was less than the value specified by manufacturers. It should be noted that the specified strength of grout materials seemed less than 9000 psi in most of cases where significant variability or smaller strength was observed.

The design compressive strength of Alaska DBT girders is usually in a range of 7500 – 8500 psi. The actual strength can be greater than the design value. For example, the measured 28-day strength by the research team was 9119 psi. The DOT&PF specifications require the 28-day strength of grout to be 9000 psi or above in order to prevent grout failure. In Matsumoto et al. (2001), additional 1000 psi was added to the strength of connecting concrete members to determine the required grout strength. The increase was to consider the likelihood that the actual strength can exceed the design strength. Also, a conversion factor of 1.25 was multiplied to the increased strength since grout test used cube specimens while concrete test used cylindrical specimens. The test results from cylindrical specimens are typically 80% results from cube specimens. If the same approach is used, the specified compressive strength of cube grout specimens in DOT&PF specifications is 1.25(8500+1000) = 11875 psi. The 28-day strength requirement in the DOT&PF specifications may require a review.

In addition, not only the 28-day strength requirement but also earlier day strength requirements need to be added in DOT&PF specifications. Early curing day strength requirement in ASTM C1107 is not for high strength grout materials. Also, performance requirement for dimensional stability might be revised. Varga and Graybeal (2015) argued that performance requirement in ASTM C1107 are not sufficient to provide a proper level of dimensional stability.

The different in compressive strength test results between 2 in. × 2 in. cube specimens and 4 in. × 8 in. cylindrical specimens is widely known. The results from cylindrical specimens are 75 – 80% the results from cube specimens. An ODOT study showed that 28-day strength from 3 in. × 6 in. cylindrical specimens was greater than strength from 2 in. × 2 in. cube specimens. But the difference was less than 3%. Comparison between 2 in. × 2 in. cube specimens and 4 in. × 8 in. cylindrical specimens of UHPC in (Graybeal and Davis 2008) showed that the difference depended on UHPC materials. For high strength grout materials, the difference has not been well quantified yet. More test results should be collected to understand difference in compressive strength test results from different sizes of specimens.

As important factors during construction of grout, studies in reviewed literature emphasized the amount of water mixed with grout and its control, maintaining consistency of grout mix by using the flow cone tests at site, and keeping the working time (pot life) in grout operation. Those factors are directly related to the compressive strength of grout and the variability of compressive strength.

APPENDIX B. SURVEY RESULTS

Surveys were distributed to a number of professionals, most of which were a part of Bridge and Materials Sections of other state DOTs, in order to collect information regarding grout materials used in projects. Survey questions pertain to types of grout materials used and specifications followed, including construction specifications, specifications for compressive strength testing, and variability specifications. Relevant DOTs' specifications can be found in Appendix C, and the survey questions can be found at the end of this appendix.

B.1 Supplier in Alaska

In a response from Mr. Michael Hanel who previously worked for Polar Supply in Anchorage and supplied grout materials for various AK projects, he experienced that test results have fallen below minimum required specifications due to various reasons. Non-shrink grouts on DBT girders have been the standard for years, and products made by various companies have been used. For many years, Dayton Superior High Performance Grout was used almost exclusively on bridge construction. There were other grouts available including Five Star Products, Sika, BASF, WR Meadows and others. Grouts made by Mapei were supplied by another supplier in Anchorage (Anchorage Sand and Gravel) and used in bridge projects.

Mr. Hanel mentioned that main reason for grout failure was improper mixing caused by either improper equipment (mixer) or excessive water content. He also experienced situations where a local water source was contaminated and resulted in problems and failures. In his opinion, temperature during specimen cast could cause problems so that cube specimens should be protected as much as possible while they are being cast. A cover plate must be used in a cube mold or results will not be accurate. For example, Dayton Superior High Performance 1107 Grout has expansive agents which counteracts the normal shrinkage in Portland cement mixes and the plate confines the grout and allows this expansion to take place as intended by the manufacturer. Also, it was mentioned that transporting freshly cast cubes in the back of a pickup and driving over a rough ungraded road before the grout has cured can cause problems.

B.2 Washington State DOT

Washington State DOT has specified a number of grout mixes in their bridge construction, most of which fall under the non-shrink category. Some common manufacturers and products include Dayton Superior Sure Grip High Performance Grout and Five Star Fluid Grout 100. Per articles 6-02.3(25) and 9-20.3(2) of the WSDOT Standard Specification (WSDOT 2016), when constructing girder to girder connections in the state, deflections shall be equalized in accordance with the contractor's equalization plan if need be, then intermediate diaphragms and weld ties shall be placed. Welding ground is directly attached to the steel plates being welded and keyways receiving grout are filled flush using a non-shrink grout with a 7-day compressive strength of 4000 psi. Equalization equipment is not moved and other construction is not placed until the intermediate diaphragms and keyway grout have reached a minimum compressive strength of 2500 psi (WSDOT Standard Specification, 6-02.3(25) and 9-20.3(2), 2016).

Grouts used by WSDOT are mixtures of Portland or blended hydraulic cement and water with or without aggregate and admixtures including fly ash or concrete admixtures. The grout can be a manufacturer's pre-packaged grout or mix designed and submitted by contractor. All pre-packaged grout are used according to the manufacturers' recommendation, including shelf life, mixing, surface preparation, and curing. All 2 in. cube specimens molded in the field are made in accordance with WSDOT T 813 in the WSDOT Materials Manual and tested in accordance with AASHTO T 106 when no aggregate is present in the grout mix design (WSDOT Standard Specification 9-20.3, 2016). Tests of field fabricated and laboratory fabricated 2 in. cube specimens often yield data with minimum variability with no or little reports of issues with strength.

B.3 Oregon DOT

For bridge construction applications, Oregon Department of Transportation (ODOT) only uses cement based grout mixes in accordance with ASTM C1107 or PTI M55.1 for post tensioned structures. ODOT uses grout that is covered by Oregon Standard Specification Section 02080 which covers compressive strength specifications of grout materials (ODOT 2015). ODOT also takes into consideration the grout manufacturers' recommendations for use. ODOT tests 2 in. cube grout specimens according to ASTM C109 and specifies a minimum 28-day compressive strength of 5000 psi according to ASTM C1107. ODOT does not have issues related with minimum variability or failing to meet minimum required compressive strength. QC/QA procedures include standard measurements of density, flow, and bleed.

B.4 Wyoming DOT

Wyoming Department of Transportation (WYDOT) has only used cementitious grout materials for bridge applications. WYDOT uses the Wyoming Standard Specifications for Road and Bridge Construction Special Provisions (WYDOT 2010) to produce grout used on bridge construction. This specification also serves as the construction specification for the grout materials in the state. WYDOT uses cube specimens according to AASHTO T106 for compressive strength testing, and the minimum required compressive strength specified by WYDOT varies depending on project. The survey respondent for WYDOT was not aware of any issues with reliability or failing to meet minimum required compressive strength, and stated that there are no QC/QA tests used to assess grout materials.

B.5 Minnesota DOT

Minnesota Department of Transportation (MNDOT) uses only standard non-shrink grout mixes for bridge applications. Grouts used are specified by ASTM C1107 for producing grout, and specimens are 2 in. cubes according to ASTM C109. Compressive strength specified varies by project. The survey respondent for MNDOT was not aware of any issues with reliability or failing to meet minimum required compressive strength, and stated that there are no QC/QA tests used to assess grout materials.

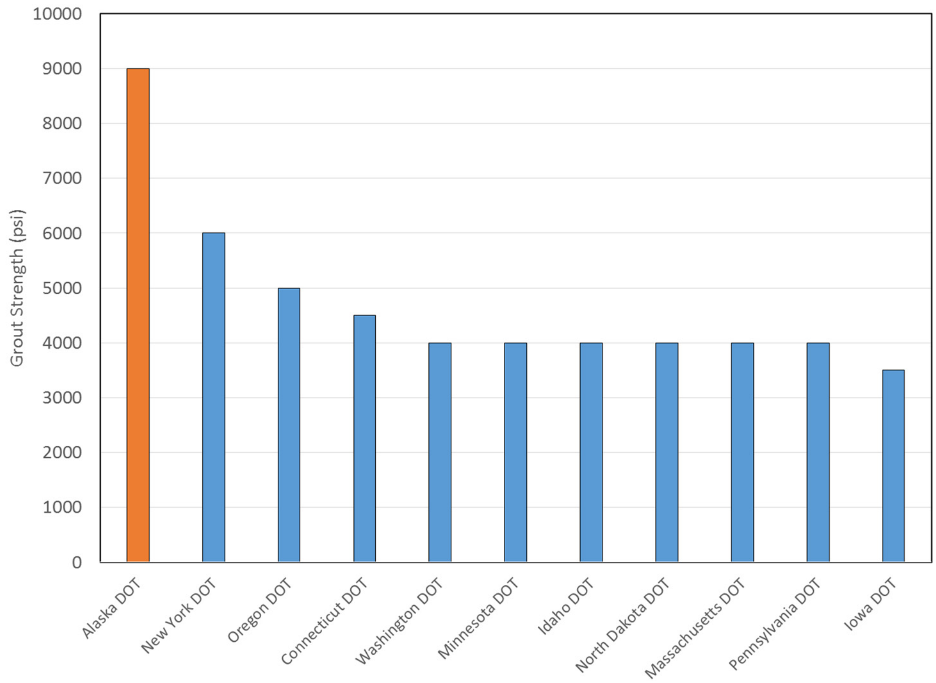
B.6 FHWA Research and Development

FHWA Research and Development has tested many grouts and ultra-high performance concretes (UHPC) in regards to assessing properties relevant to connections between prefabricated bridge elements. Most grouts and UHPCs were fabricated using manufacturer's instructions. Specimens tested are under ASTM C109 for grouts. UHPC are tested under ASTM C1856, which is slightly modified from ASTM C39 (Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens) to test UHPC properly. They did not have experience with significant variability in compressive strength test results. There was prominent call to other factors such as interface bond and dimensional stability.

B.7 Survey Result Summary

Out of all responses, every agency uses cement based grout as the standard grout for common application in bridge construction and 60 percent of these grout mixes are reported to be non-shrink. Each state DOT uses construction specifications from their own set of standard construction specifications. 60 percent of agencies use ASTM C1107 as the standard for producing grout materials to be used in construction, while Washington and Wyoming DOTs use their own standard specifications. No agency reported using any non-cementitious grout materials such as epoxy grouts.

When molding specimens most agencies (60 percent) use cube molds according to ASTM C109. Washington and Wyoming DOTs use cube molds according to AASHTO T106. Minimum specified compressive strength for grout cubes are reported to vary per application for Wyoming and Minnesota DOTs. Minimum compressive strength is 5000 psi and 4000 psi for Oregon and Washington DOTs, respectively. In Figure B-1, minimum compressive strengths of grout are compared. Compressive strength from several other DOTs are also included in the figure. In the Alaska DOT Standard Specifications, the minimum strength for keyway grout is 9000 psi which is much higher than other state DOTs. It should be noted that 6000 psi is for 7-day strength in New York State DOT (NYSDOT 2018). The 28-day strength of the same grout may reach 9000 psi.



NOTE: 1. 7-day strength for New York State DOT and Iowa DOT; 2. 5000 psi minimum strength for R3 type in North Dakota DOT

Figure B-1. Comparison of minimum grout compressive strength

Survey of Current Practice:
Variability of Compressive Strength of Non-Shrink Grout Specimen

Background

In Alaska, 80% of recently constructed bridges are of precast, prestressed decked bulb-tee (DBT) girder type (spans are up to 145 feet) due to their low cost and to accommodate Alaska's short construction window and the subsequent need for accelerated bridge construction. High-strength, non-shrink grout is typically used in constructing the longitudinal keyway joints between adjacent precast girders. Per Alaska Department of Transportation & Public Facilities (ADOT&PF)'s Standard Specifications for Highway Construction, the grout should be "non-shrink, non-corrosive, non-metallic, cement-based grout meeting ASTM C1107, except develop a 28- day compressive strength of at least 9,000 psi when tested according to AASHTO T106 or ASTM C109." However, past experiences indicated that the test results (e.g., 28-day compressive strength of 2 in. ×2 in. cube specimens) had larger variations than the variability requirement in ASTM C109.

Our research team from the University of Alaska Fairbanks is conducting a study with a number of tasks, aiming at verifying the variability and discrepancy in compressive strength results of grout materials used in current bridge construction, and identifying the cause(s) of the variability in high-strength grout test results. This survey is to collect experiences and knowledge on relevant practice and construction techniques for grouting in bridge construction from various practitioners and agencies.

Please complete and return this survey by **05/19/17**. Your valuable input and feedback will be highly appreciated. Please feel free to contact us if you have any questions or if more information is needed.

Jenny Liu, Ph.D., P.E. (jliu6@alaska.edu, 907-474-5764) and Il-Sang Ahn, Ph.D., P.E. (ahn.ilsang@alaska.edu, 907-474-6733)
Department of Civil and Environmental Engineering
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Questions

1. What kinds of grout (or alternate materials other than the typical non-shrink cement based grout) have you used in bridge construction? Please name the products and manufacturers.

2. Which construction specification have you used for grout materials?

3. Which specification (e.g., manufacturer's written instructions) have you used to produce the grout (mixing, consolidating, placing, and curing) for testing?

4. What type of test specimens for the compressive strength test of the grout?

5. What is the compressive strength requirement for the grout (or alternate material) practiced in your agency? Which specification have you used for the compressive strength test?

6. Have your tests often yielded data results with minimum variability? Are there any other issues you have encountered in terms of strength data results?

7. If there are issues, please identify the issues and describe possible reasons to cause these issues.

8. What are other QC/QA tests you have conducted to assess the grout materials for bridge construction? Does your agency regulate any special rules for casting, initial-curing, and transporting grout specimens made in the field?

9. (Follow-up question of No. 5) If ASTM C109 has been used in your agency, do you have any experience that the variability criteria were not satisfied? In ASTM C109, it was specified that "13.2: The maximum permissible range between specimens from the same mortar batch, at the same test age is 8.7 % of the average when three cubes represent a test age and 7.6 % when two cubes represent a test age (Note 10)."

____

____

10. Do you have any other comments, suggestions or recommendations?

____

____

11. Have you used any non-cementitious grouts (e.g., epoxy grout)? If so, what material specifications and specific products have been used?

____

____

Thank you very much for your time.

Survey completed by: ______________________________ (Name)

______________________________ (Affiliation)

______________________________ (Tel number, e-mail address)

APPENDIX C.

SELECTED DOTS' SPECIFICATIONS OF GROUT MATERIALS AND OPERATIONS

9-20.3 Grout

Grout is a mixture of Portland or blended hydraulic cement and water with or without aggregates and with or without admixtures. Grout may also contain fly ash and/or concrete admixtures. Grout may be a Contractor's submitted mix design or a Manufacturer's prepackaged grout product.

All prepackaged grouts shall be used in accordance with the manufacturer's recommendations, including but not limited to, shelf life, mixing, surface preparation, and curing.

Where required, all 2-inch cube specimens fabricated in the field shall be made in accordance with WSDOT T 813. All 2-inch cube specimens fabricated in a laboratory shall be made in accordance with FOP for AASHTO T 106. All 2-inch cube specimens shall be tested in accordance with FOP for AASHTO T 106.

When coarse aggregate is used, specimens shall be fabricated in accordance with FOP for AASHTO T 23 and tested in accordance with AASHTO T 22.

9-20.3(1) Grout Type 1 for Post-Tensioning Applications

Grout Type 1 shall be a Class C prepackaged, pumpable, nonbleed, nonshrink, and high-strength material conforming to the requirements of AASHTO *LRFD Bridge Construction Specifications* Section 10.9.3. The water/cement ratio shall not exceed 0.45.

9-20.3(2) Grout Type 2 for Nonshrink Applications

Grout Type 2 shall be a nonshrink, prepackaged material meeting the requirements of ASTM C1107. The minimum compressive strength shall be 4,000 psi at 7 days.

9-20.3(3) Grout Type 3 for Unconfined Bearing Pad Applications

Grout Type 3 shall be a prepackaged material meeting the requirements of ASTM C928 – Table 1, R2 Concrete or Mortar.

9-20.3(4) Grout Type 4 for Multipurpose Applications

Grout Type 4 shall be a multipurpose grout material for structural and nonstructural applications. The grout shall be produced using portland cement Type I/II. The water to cementitious material ratio shall not exceed 0.45 and water-reducing admixtures may be used. Multipurpose grout may be extended up to three parts fine aggregate to one part cement. The minimum compressive strength shall be 4,000 psi at 7 days. Substitution of fly ash for cement is allowed up to 20 percent.

9-20.4 Mortar

Mortar shall be material made from Portland or blended hydraulic cement, water, and fine aggregate.

9-20.4(1) Fine Aggregate for Mortar

Fine Aggregate for mortar shall conform to the requirements of Section 9-03.2.

9-20.4(2) Mortar Type 1 for Concrete Surface Finish

Mortar Type 1 for concrete surface finishing shall be either prepackaged or a Contractor-recommended blend of portland cement Type I/II and fine aggregate conforming to Section 9-20.4(1). If the Class 1 concrete surface finishing mortar is a Contractor-recommended blend, it shall conform to the sand-to-cement ratios specified in Section 6-02.3(14)A.

9-20.4(3) Mortar Type 2 for Masonry Applications

Mortar Type 2 for masonry shall be either prepackaged or a Contractor-recommended blend of portland cement Type I/II and fine aggregate conforming to Section 9-20.4(1).

- Submit stamped calculations that predict the effect of temporary strands on initial and long term girder Camber according to 00150.35.

Damaged members will be rejected. Replace damaged members, or if allowed by the Engineer, repair damaged members to the Engineer's satisfaction at no additional cost to the Agency.

(d) Erecting and Bracing - After a member has been erected and until it is secured to the Structure, provide temporary bracing as necessary to resist wind or other loads. Provide the Engineer with an erection plan and bracing details at least 2 days prior to erecting girders. Bracing details are not necessary for side-by-side slab and box beam construction.

00550.50 Tie Rods - Furnish tie rods according to the Plans and Section 02560. Install as follows:

- Clean and lubricate tie rods and nuts before installation.
- Lubricate galvanized tie rods and nuts with a lubricant from the QPL containing dye that visibly contrasts with the color of galvanizing or coating.
- Install compressible washer type direct tension indicators under the turned nuts and tighten the nuts as recommended by the manufacturer until the gaps in the indicators are nil or as shown. A nil gap is defined as a gap when the number of spaces between the protrusions of a direct tension indicator in which the 0.005 inch feeler gauge is refused at each tie rod equals or exceeds 2, 3, 3, 4, or 4, when the number of spaces between protrusions in the direct tension indicator are 4, 5, 6, 7, or 8, respectively, and a visible gap exists in at least one space.

00550.51 Keyway Grouting for Slabs, Box Beams, and Integral Deck Members - After forms have been removed from slabs, box beams and integral deck bulb tees, sandblast all keyways to remove residual form oil and any other foreign material. After the members are in place and the tie rods are tensioned (for slabs and box beams) or welded connections are made (integral deck bulb tee girders), clean the keyways of all foreign material and keep moist for 24 hours before grouting. For slabs and box beams, after the tie rods are tensioned, seal the space remaining at the bottom of the keyways with a backer rod as shown before grouting.

Do not pour keyway grout unless the air temperature is above 45 °F and at or below the maximum air temperature recommended by the manufacturer. Water cure grout for the period of time indicated by the manufacturer.

00550.52 Poured Joint Filler for Integral Deck Members with AC Wearing Surface - After grout is poured to the level of the keyway shown for slabs and box beams, remove loose grout, and other foreign material from exposed keyway walls. After keyway grout is fully cured, dry surfaces to be sealed immediately before installing poured joint filler.

Install poured joint filler according to the manufacturer's directions. Cure the filler sufficiently to resist the pressures and temperatures of the paving operation before the wearing surface is placed.

00550.53 Differential Camber Correction for Integral Deck Members with No Asphalt Concrete Wearing Surface - Correct differential Camber between adjacent slabs, box beams or integral deck bulb tees in a span (measured in place at the site) if the variance between adjacent members or stages is 1/2 inch or more at any place along the top edge corners.

Equalize the Camber differences by either patching with an epoxy or non-epoxy grout or other approved method, at no additional cost to the Agency. Before patching, clean the area by sandblasting. Water cure the patch for the period of time indicated by the manufacturer. If patching is used, slope it away from the joint on a 1V:6H Slope or flatter.

Section 02080 - Grout

Description

02080.00 Scope - This Section includes the requirements for epoxy, non-epoxy, keyway, and portland cement grout.

Materials

02080.10 Epoxy Grout - Furnish epoxy grout from the QPL.

02080.20 Non-Epoxy Grout - Furnish non-epoxy grout from the QPL.

02080.30 Keyway Grout - Furnish grout used in the keyways of precast prestressed concrete members that is non-shrink, nonferrous, non-epoxy grout with a minimum design strength of 5,000 psi in 28 Calendar Days. Furnish keyway grout from the QPL and use according to the manufacturer's recommendations.

02080.40 Portland Cement Grout - Furnish portland cement grout consisting of one part portland cement and three parts sand by weight, thoroughly mixed with a minimum amount of water to produce a thick, creamy consistency. Sand shall meet the requirements of 02690.30 and cement shall meet the requirements of Section 02010.

02080.50 Tendon Grout - Furnish tendon grout from the QPL that meets vertical rise requirements.

02080.60 Structural Grout - Furnish structural grout from the QPL and use according to the manufacturer's recommendations. Grout shall be non-shrink, nonferrous, non-epoxy grout with a minimum design strength of 5,000 psi at 28 Calendar Days.

SECTION 819
Grout

819.1 Grout

819.1.1 Sand-Cement Grout

1 For sand-cement grout, provide and use grout composed of portland cement in accordance with Subsection 801.1, Portland Cement, sand in accordance with Subsection 803.3, Aggregate for Mortar, and only enough water to allow placing and packing; ensure a proportion of cement to sand, measured by volume, of 1:2. Mix approximately 45 minutes before use.

819.1.2 Nonshrink Grout

1 For nonshink grout, provide and use a product in accordance with ASTM C 1107. Do not add aluminum.

819.2 Epoxy Resin Grout

1 For epoxy resin grout, provide and use a product in accordance with AASHTO M 235, type IV, grade 2; use grade 3 for horizontal holes and vertical and overhead applications. Provide a class of grout suitable for the temperature of the concrete at the time of use. The engineer may approve the use of other polymer adhesives.

APPENDIX D: SUMMARY OF TEST RESULTS

Specimen ID	Round	Cast Date	Grout	Consistency	Test Date	Load (lb)
UAF-B-0420-1	1	4/20/18	Sure-Grip	Fluid	4/27/18	38965
UAF-B-0420-2	1	4/20/18	Sure-Grip	Fluid	4/27/18	38935
UAF-B-0420-3	1	4/20/18	Sure-Grip	Fluid	4/27/18	37120
AKDOT-X-0420-1	1	4/20/18	Sure-Grip	Fluid	4/27/18	37650
AKDOT-X-0420-2	1	4/20/18	Sure-Grip	Fluid	4/27/18	37540
AKDOT-X-0420-3	1	4/20/18	Sure-Grip	Fluid	4/27/18	36960
AKDOT-Y-0420-1	1	4/20/18	Sure-Grip	Fluid	4/27/18	38290
AKDOT-Y-0420-2	1	4/20/18	Sure-Grip	Fluid	4/27/18	37005
AKDOT-Y-0420-3	1	4/20/18	Sure-Grip	Fluid	4/27/18	37970
AKDOT-Z-0420-1	1	4/20/18	Sure-Grip	Fluid	4/27/18	36495
AKDOT-Z-0420-2	1	4/20/18	Sure-Grip	Fluid	4/27/18	36655
AKDOT-Z-0420-3	1	4/20/18	Sure-Grip	Fluid	4/27/18	38865
UAF-B-0420-4	1	4/20/18	Sure-Grip	Fluid	5/18/18	42725
UAF-B-0420-5	1	4/20/18	Sure-Grip	Fluid	5/18/18	42335
UAF-B-0420-6	1	4/20/18	Sure-Grip	Fluid	5/18/18	43170
AKDOT-X-0420-4	1	4/20/18	Sure-Grip	Fluid	5/18/18	42405
AKDOT-X-0420-5	1	4/20/18	Sure-Grip	Fluid	5/18/18	43560
AKDOT-X-0420-6	1	4/20/18	Sure-Grip	Fluid	5/18/18	44250
AKDOT-Y-0420-4	1	4/20/18	Sure-Grip	Fluid	5/18/18	41740
AKDOT-Y-0420-5	1	4/20/18	Sure-Grip	Fluid	5/18/18	41835
AKDOT-Y-0420-6	1	4/20/18	Sure-Grip	Fluid	5/18/18	40730
AKDOT-Z-0420-4	1	4/20/18	Sure-Grip	Fluid	5/18/18	41810
AKDOT-Z-0420-5	1	4/20/18	Sure-Grip	Fluid	5/18/18	42620
AKDOT-Z-0420-6	1	4/20/18	Sure-Grip	Fluid	5/18/18	42990
UAF-A-0425-1	1	4/25/18	Sure-Grip	Fluid	5/2/18	33080
UAF-A-0425-2	1	4/25/18	Sure-Grip	Fluid	5/2/18	34485
UAF-A-0425-3	1	4/25/18	Sure-Grip	Fluid	5/2/18	36085
AKDOT-S-0425-1	1	4/25/18	Sure-Grip	Fluid	5/2/18	35045
AKDOT-S-0425-2	1	4/25/18	Sure-Grip	Fluid	5/2/18	35205
AKDOT-S-0425-3	1	4/25/18	Sure-Grip	Fluid	5/2/18	34495
AKDOT-T-0425-1	1	4/25/18	Sure-Grip	Fluid	5/2/18	35800
AKDOT-T-0425-2	1	4/25/18	Sure-Grip	Fluid	5/2/18	37545
AKDOT-T-0425-3	1	4/25/18	Sure-Grip	Fluid	5/2/18	36855
AKDOT-S-0425-4	1	4/25/18	Sure-Grip	Fluid	5/23/18	41880
AKDOT-S-0425-5	1	4/25/18	Sure-Grip	Fluid	5/23/18	37630
AKDOT-S-0425-6	1	4/25/18	Sure-Grip	Fluid	5/23/18	42165
AKDOT-T-0425-4	1	4/25/18	Sure-Grip	Fluid	5/23/18	42910
AKDOT-T-0425-5	1	4/25/18	Sure-Grip	Fluid	5/23/18	43245
AKDOT-T-0425-6	1	4/25/18	Sure-Grip	Fluid	5/23/18	44190
UAF-A-0427-1	1	4/27/18	Sure-Grip	Flowable	5/4/18	39780
UAF-A-0427-2	1	4/27/18	Sure-Grip	Flowable	5/4/18	42460
UAF-A-0427-3	1	4/27/18	Sure-Grip	Flowable	5/4/18	42930
AKDOT-X-0427-1	1	4/27/18	Sure-Grip	Flowable	5/4/18	40560
AKDOT-X-0427-2	1	4/27/18	Sure-Grip	Flowable	5/4/18	39370

Specimen ID	Round	Cast Date	Grout	Consistency	Test Date	Load (lb)
AKDOT-X-0427-3	1	4/27/18	Sure-Grip	Flowable	5/4/18	42140
AKDOT-Y-0427-1	1	4/27/18	Sure-Grip	Flowable	5/4/18	42990
AKDOT-Y-0427-2	1	4/27/18	Sure-Grip	Flowable	5/4/18	40610
AKDOT-Y-0427-3	1	4/27/18	Sure-Grip	Flowable	5/4/18	42365
AKDOT-Z-0427-1	1	4/27/18	Sure-Grip	Flowable	5/4/18	42805
AKDOT-Z-0427-2	1	4/27/18	Sure-Grip	Flowable	5/4/18	43495
AKDOT-Z-0427-3	1	4/27/18	Sure-Grip	Flowable	5/4/18	40985
UAF-A-0427-4	1	4/27/18	Sure-Grip	Flowable	5/25/18	49765
UAF-A-0427-5	1	4/27/18	Sure-Grip	Flowable	5/25/18	46245
UAF-A-0427-6	1	4/27/18	Sure-Grip	Flowable	5/25/18	44940
AKDOT-X-0427-4	1	4/27/18	Sure-Grip	Flowable	5/25/18	50070
AKDOT-X-0427-5	1	4/27/18	Sure-Grip	Flowable	5/25/18	47715
AKDOT-X-0427-6	1	4/27/18	Sure-Grip	Flowable	5/25/18	49780
AKDOT-Y-0427-4	1	4/27/18	Sure-Grip	Flowable	5/25/18	49985
AKDOT-Y-0427-5	1	4/27/18	Sure-Grip	Flowable	5/25/18	50030
AKDOT-Y-0427-6	1	4/27/18	Sure-Grip	Flowable	5/25/18	51045
AKDOT-Z-0427-4	1	4/27/18	Sure-Grip	Flowable	5/25/18	48545
AKDOT-Z-0427-5	1	4/27/18	Sure-Grip	Flowable	5/25/18	50195
AKDOT-Z-0427-6	1	4/27/18	Sure-Grip	Flowable	5/25/18	50140
AKDOT-S-0502-1	1	5/2/18	Sure-Grip	Flowable	5/9/18	43310
AKDOT-S-0502-2	1	5/2/18	Sure-Grip	Flowable	5/9/18	40970
AKDOT-S-0502-3	1	5/2/18	Sure-Grip	Flowable	5/9/18	41205
AKDOT-T-0502-1	1	5/2/18	Sure-Grip	Flowable	5/9/18	36095
AKDOT-T-0502-2	1	5/2/18	Sure-Grip	Flowable	5/9/18	34880
AKDOT-T-0502-3	1	5/2/18	Sure-Grip	Flowable	5/9/18	34780
AKDOT-S-0502-4	1	5/2/18	Sure-Grip	Flowable	5/30/18	45965
AKDOT-S-0502-5	1	5/2/18	Sure-Grip	Flowable	5/30/18	42345
AKDOT-S-0502-6	1	5/2/18	Sure-Grip	Flowable	5/30/18	47540
AKDOT-T-0502-4	1	5/2/18	Sure-Grip	Flowable	5/30/18	45375
AKDOT-T-0502-5	1	5/2/18	Sure-Grip	Flowable	5/30/18	43080
AKDOT-T-0502-6	1	5/2/18	Sure-Grip	Flowable	5/30/18	43345
UAF-B-0504-1	1	5/4/18	Sure-Grip	Fluid	5/11/18	37100
UAF-B-0504-2	1	5/4/18	Sure-Grip	Fluid	5/11/18	36685
UAF-B-0504-3	1	5/4/18	Sure-Grip	Fluid	5/11/18	38035
AKDOT-X-0504-1	1	5/4/18	Sure-Grip	Fluid	5/11/18	35750
AKDOT-X-0504-2	1	5/4/18	Sure-Grip	Fluid	5/11/18	37280
AKDOT-X-0504-3	1	5/4/18	Sure-Grip	Fluid	5/11/18	37205
AKDOT-Y-0504-1	1	5/4/18	Sure-Grip	Fluid	5/11/18	36555
AKDOT-Y-0504-2	1	5/4/18	Sure-Grip	Fluid	5/11/18	36505
AKDOT-Y-0504-3	1	5/4/18	Sure-Grip	Fluid	5/11/18	35310
AKDOT-Z-0504-1	1	5/4/18	Sure-Grip	Fluid	5/11/18	36020
AKDOT-Z-0504-2	1	5/4/18	Sure-Grip	Fluid	5/11/18	36945
AKDOT-Z-0504-3	1	5/4/18	Sure-Grip	Fluid	5/11/18	35785
UAF-B-0504-4	1	5/4/18	Sure-Grip	Fluid	6/1/18	39365

Specimen ID	Round	Cast Date	Grout	Consistency	Test Date	Load (lb)
UAF-B-0504-5	1	5/4/18	Sure-Grip	Fluid	6/1/18	42125
UAF-B-0504-6	1	5/4/18	Sure-Grip	Fluid	6/1/18	40640
AKDOT-X-0504-4	1	5/4/18	Sure-Grip	Fluid	6/1/18	41530
AKDOT-X-0504-5	1	5/4/18	Sure-Grip	Fluid	6/1/18	41885
AKDOT-X-0504-6	1	5/4/18	Sure-Grip	Fluid	6/1/18	41525
AKDOT-Y-0504-4	1	5/4/18	Sure-Grip	Fluid	6/1/18	41880
AKDOT-Y-0504-5	1	5/4/18	Sure-Grip	Fluid	6/1/18	40695
AKDOT-Y-0504-6	1	5/4/18	Sure-Grip	Fluid	6/1/18	38830
AKDOT-Z-0504-4	1	5/4/18	Sure-Grip	Fluid	6/1/18	38905
AKDOT-Z-0504-5	1	5/4/18	Sure-Grip	Fluid	6/1/18	40985
AKDOT-Z-0504-6	1	5/4/18	Sure-Grip	Fluid	6/1/18	40505
UAF-B-0509-1	1	5/9/18	Sure-Grip	Fluid	5/16/18	38000
UAF-B-0509-2	1	5/9/18	Sure-Grip	Fluid	5/16/18	35335
UAF-B-0509-3	1	5/9/18	Sure-Grip	Fluid	5/16/18	36150
AKDOT-S-0509-1	1	5/9/18	Sure-Grip	Fluid	5/16/18	34760
AKDOT-S-0509-2	1	5/9/18	Sure-Grip	Fluid	5/16/18	37170
AKDOT-S-0509-3	1	5/9/18	Sure-Grip	Fluid	5/16/18	34395
UAF-B-0509-4	1	5/9/18	Sure-Grip	Fluid	6/6/18	42830
UAF-B-0509-5	1	5/9/18	Sure-Grip	Fluid	6/6/18	44035
UAF-B-0509-6	1	5/9/18	Sure-Grip	Fluid	6/6/18	44435
AKDOT-S-0509-4	1	5/9/18	Sure-Grip	Fluid	6/6/18	38740
AKDOT-S-0509-5	1	5/9/18	Sure-Grip	Fluid	6/6/18	37970
AKDOT-S-0509-6	1	5/9/18	Sure-Grip	Fluid	6/6/18	40165
UAF-B-0522-1	2	5/22/18	Sure-Grip	Fluid	5/23/18	23805
UAF-B-0522-2	2	5/22/18	Sure-Grip	Fluid	5/23/18	23975
UAF-B-0522-3	2	5/22/18	Sure-Grip	Fluid	5/23/18	24545
UAF-B-0522-4	2	5/22/18	Sure-Grip	Fluid	5/25/18	31375
UAF-B-0522-5	2	5/22/18	Sure-Grip	Fluid	5/25/18	31655
UAF-B-0522-6	2	5/22/18	Sure-Grip	Fluid	5/25/18	29995
UAF-B-0522-7	2	5/22/18	Sure-Grip	Fluid	5/23/18	23280
UAF-B-0522-8	2	5/22/18	Sure-Grip	Fluid	5/23/18	22895
UAF-B-0522-9	2	5/22/18	Sure-Grip	Fluid	5/23/18	23995
UAF-B-0522-10	2	5/22/18	Sure-Grip	Fluid	5/25/18	28645
UAF-B-0522-11	2	5/22/18	Sure-Grip	Fluid	5/25/18	30930
UAF-B-0522-12	2	5/22/18	Sure-Grip	Fluid	5/25/18	30075
UAF-B-0522-13	2	5/22/18	Sure-Grip	Fluid	5/29/18	33990
UAF-B-0522-14	2	5/22/18	Sure-Grip	Fluid	5/29/18	34095
UAF-B-0522-15	2	5/22/18	Sure-Grip	Fluid	5/29/18	32890
UAF-B-0522-16	2	5/22/18	Sure-Grip	Fluid	6/19/18	40450
UAF-B-0522-17	2	5/22/18	Sure-Grip	Fluid	6/19/18	35800
UAF-B-0522-18	2	5/22/18	Sure-Grip	Fluid	6/19/18	40475
UAF-B-0522-19	2	5/22/18	Sure-Grip	Fluid	5/29/18	32720
UAF-B-0522-20	2	5/22/18	Sure-Grip	Fluid	5/29/18	32155
UAF-B-0522-21	2	5/22/18	Sure-Grip	Fluid	5/29/18	33070

Specimen ID	Round	Cast Date	Grout	Consistency	Test Date	Load (lb)
UAF-B-0522-22	2	5/22/18	Sure-Grip	Fluid	6/19/18	40480
UAF-B-0522-23	2	5/22/18	Sure-Grip	Fluid	6/19/18	39145
UAF-B-0522-24	2	5/22/18	Sure-Grip	Fluid	6/19/18	42025
UAF-B-0524-1	2	5/24/18	Sure-Grip	Flowable	5/25/18	30430
UAF-B-0524-2	2	5/24/18	Sure-Grip	Flowable	5/25/18	30170
UAF-B-0524-3	2	5/24/18	Sure-Grip	Flowable	5/25/18	30025
UAF-B-0524-4	2	5/24/18	Sure-Grip	Flowable	5/27/18	36345
UAF-B-0524-5	2	5/24/18	Sure-Grip	Flowable	5/27/18	35505
UAF-B-0524-6	2	5/24/18	Sure-Grip	Flowable	5/27/18	36415
UAF-B-0524-7	2	5/24/18	Sure-Grip	Flowable	5/25/18	28870
UAF-B-0524-8	2	5/24/18	Sure-Grip	Flowable	5/25/18	29805
UAF-B-0524-9	2	5/24/18	Sure-Grip	Flowable	5/25/18	30005
UAF-B-0524-10	2	5/24/18	Sure-Grip	Flowable	5/27/18	32475
UAF-B-0524-11	2	5/24/18	Sure-Grip	Flowable	5/27/18	34730
UAF-B-0524-12	2	5/24/18	Sure-Grip	Flowable	5/27/18	34890
UAF-B-0524-13	2	5/24/18	Sure-Grip	Flowable	5/31/18	43325
UAF-B-0524-14	2	5/24/18	Sure-Grip	Flowable	5/31/18	43490
UAF-B-0524-15	2	5/24/18	Sure-Grip	Flowable	5/31/18	43955
UAF-B-0524-16	2	5/24/18	Sure-Grip	Flowable	6/21/18	51480
UAF-B-0524-17	2	5/24/18	Sure-Grip	Flowable	6/21/18	49510
UAF-B-0524-18	2	5/24/18	Sure-Grip	Flowable	6/21/18	50750
UAF-B-0524-19	2	5/24/18	Sure-Grip	Flowable	5/31/18	41925
UAF-B-0524-20	2	5/24/18	Sure-Grip	Flowable	5/31/18	39075
UAF-B-0524-21	2	5/24/18	Sure-Grip	Flowable	5/31/18	41130
UAF-B-0524-22	2	5/24/18	Sure-Grip	Flowable	6/21/18	52880
UAF-B-0524-23	2	5/24/18	Sure-Grip	Flowable	6/21/18	52600
UAF-B-0524-24	2	5/24/18	Sure-Grip	Flowable	6/21/18	50415
UAF-A-0601-1	2	6/1/18	Sure-Grip	Fluid	6/2/18	21720
UAF-A-0601-2	2	6/1/18	Sure-Grip	Fluid	6/2/18	21550
UAF-A-0601-3	2	6/1/18	Sure-Grip	Fluid	6/2/18	21170
UAF-A-0601-4	2	6/1/18	Sure-Grip	Fluid	6/4/18	27930
UAF-A-0601-5	2	6/1/18	Sure-Grip	Fluid	6/4/18	26050
UAF-A-0601-6	2	6/1/18	Sure-Grip	Fluid	6/4/18	25530
UAF-A-0601-7	2	6/1/18	Sure-Grip	Fluid	6/2/18	19645
UAF-A-0601-8	2	6/1/18	Sure-Grip	Fluid	6/2/18	20850
UAF-A-0601-9	2	6/1/18	Sure-Grip	Fluid	6/2/18	20920
UAF-A-0601-10	2	6/1/18	Sure-Grip	Fluid	6/4/18	24245
UAF-A-0601-11	2	6/1/18	Sure-Grip	Fluid	6/4/18	26380
UAF-A-0601-12	2	6/1/18	Sure-Grip	Fluid	6/4/18	25780
UAF-A-0601-13	2	6/1/18	Sure-Grip	Fluid	6/8/18	31280
UAF-A-0601-14	2	6/1/18	Sure-Grip	Fluid	6/8/18	29560
UAF-A-0601-15	2	6/1/18	Sure-Grip	Fluid	6/8/18	30715
UAF-A-0601-16	2	6/1/18	Sure-Grip	Fluid	6/29/18	43690
UAF-A-0601-17	2	6/1/18	Sure-Grip	Fluid	6/29/18	42825

Specimen ID	Round	Cast Date	Grout	Consistency	Test Date	Load (lb)
UAF-A-0601-18	2	6/1/18	Sure-Grip	Fluid	6/29/18	43720
UAF-A-0601-19	2	6/1/18	Sure-Grip	Fluid	6/8/18	32000
UAF-A-0601-20	2	6/1/18	Sure-Grip	Fluid	6/8/18	30120
UAF-A-0601-21	2	6/1/18	Sure-Grip	Fluid	6/8/18	32080
UAF-A-0601-22	2	6/1/18	Sure-Grip	Fluid	6/29/18	39875
UAF-A-0601-23	2	6/1/18	Sure-Grip	Fluid	6/29/18	39810
UAF-A-0601-24	2	6/1/18	Sure-Grip	Fluid	6/29/18	41440
UAF-A-0605-1	2	6/5/18	Sure-Grip	Flowable	6/6/18	26660
UAF-A-0605-2	2	6/5/18	Sure-Grip	Flowable	6/6/18	28615
UAF-A-0605-3	2	6/5/18	Sure-Grip	Flowable	6/6/18	28960
UAF-A-0605-4	2	6/5/18	Sure-Grip	Flowable	6/8/18	32825
UAF-A-0605-5	2	6/5/18	Sure-Grip	Flowable	6/8/18	32770
UAF-A-0605-6	2	6/5/18	Sure-Grip	Flowable	6/8/18	32550
UAF-A-0605-7	2	6/5/18	Sure-Grip	Flowable	6/6/18	24145
UAF-A-0605-8	2	6/5/18	Sure-Grip	Flowable	6/6/18	24825
UAF-A-0605-9	2	6/5/18	Sure-Grip	Flowable	6/6/18	26610
UAF-A-0605-10	2	6/5/18	Sure-Grip	Flowable	6/8/18	33595
UAF-A-0605-11	2	6/5/18	Sure-Grip	Flowable	6/8/18	31620
UAF-A-0605-12	2	6/5/18	Sure-Grip	Flowable	6/8/18	34210
UAF-A-0605-13	2	6/5/18	Sure-Grip	Flowable	6/12/18	40390
UAF-A-0605-14	2	6/5/18	Sure-Grip	Flowable	6/12/18	42195
UAF-A-0605-15	2	6/5/18	Sure-Grip	Flowable	6/12/18	37435
UAF-A-0605-16	2	6/5/18	Sure-Grip	Flowable	7/3/18	49755
UAF-A-0605-17	2	6/5/18	Sure-Grip	Flowable	7/3/18	49355
UAF-A-0605-18	2	6/5/18	Sure-Grip	Flowable	7/3/18	48095
UAF-A-0605-19	2	6/5/18	Sure-Grip	Flowable	6/12/18	41200
UAF-A-0605-20	2	6/5/18	Sure-Grip	Flowable	6/12/18	38330
UAF-A-0605-21	2	6/5/18	Sure-Grip	Flowable	6/12/18	38120
UAF-A-0605-22	2	6/5/18	Sure-Grip	Flowable	7/3/18	42385
UAF-A-0605-23	2	6/5/18	Sure-Grip	Flowable	7/3/18	44805
UAF-A-0605-24	2	6/5/18	Sure-Grip	Flowable	7/3/18	46055
UAF-B-0612B2-1	2	6/12/18	Sure-Grip	Fluid	6/15/18	31485
UAF-B-0612B2-2	2	6/12/18	Sure-Grip	Fluid	6/15/18	31420
UAF-B-0612B2-3	2	6/12/18	Sure-Grip	Fluid	6/15/18	32465
UAF-B-0612B2-4	2	6/12/18	Sure-Grip	Fluid	6/19/18	37780
UAF-B-0612B2-5	2	6/12/18	Sure-Grip	Fluid	6/19/18	36570
UAF-B-0612B2-6	2	6/12/18	Sure-Grip	Fluid	6/19/18	33775
UAF-B-0612B2-7	2	6/12/18	Sure-Grip	Fluid	7/10/18	45435
UAF-B-0612B2-8	2	6/12/18	Sure-Grip	Fluid	7/10/18	41305
UAF-B-0612B2-9	2	6/12/18	Sure-Grip	Fluid	7/10/18	42210
UAF-B-0612B3-1	2	6/12/18	Sure-Grip	Fluid	6/15/18	32035
UAF-B-0612B3-2	2	6/12/18	Sure-Grip	Fluid	6/15/18	32225
UAF-B-0612B3-3	2	6/12/18	Sure-Grip	Fluid	6/15/18	32050
UAF-B-0612B3-4	2	6/12/18	Sure-Grip	Fluid	6/19/18	37910

Specimen ID	Round	Cast Date	Grout	Consistency	Test Date	Load (lb)
UAF-B-0612B3-5	2	6/12/18	Sure-Grip	Fluid	6/19/18	36405
UAF-B-0612B3-6	2	6/12/18	Sure-Grip	Fluid	6/19/18	35480
UAF-B-0612B3-7	2	6/12/18	Sure-Grip	Fluid	7/10/18	46100
UAF-B-0612B3-8	2	6/12/18	Sure-Grip	Fluid	7/10/18	45445
UAF-B-0612B3-9	2	6/12/18	Sure-Grip	Fluid	7/10/18	43755
UAF-B-0615B4-1	2	6/15/18	Sure-Grip	Fluid	6/18/18	33450
UAF-B-0615B4-2	2	6/15/18	Sure-Grip	Fluid	6/18/18	33000
UAF-B-0615B4-3	2	6/15/18	Sure-Grip	Fluid	6/18/18	32485
UAF-B-0615B4-4	2	6/15/18	Sure-Grip	Fluid	6/22/18	35755
UAF-B-0615B4-5	2	6/15/18	Sure-Grip	Fluid	6/22/18	38910
UAF-B-0615B4-6	2	6/15/18	Sure-Grip	Fluid	6/22/18	39280
UAF-B-0615B4-7	2	6/15/18	Sure-Grip	Fluid	7/13/18	42890
UAF-B-0615B4-8	2	6/15/18	Sure-Grip	Fluid	7/13/18	45905
UAF-B-0615B4-9	2	6/15/18	Sure-Grip	Fluid	7/13/18	44865
UAF-B-0615B5-1	2	6/15/18	Sure-Grip	Fluid	6/18/18	33355
UAF-B-0615B5-2	2	6/15/18	Sure-Grip	Fluid	6/18/18	32335
UAF-B-0615B5-3	2	6/15/18	Sure-Grip	Fluid	6/18/18	31200
UAF-B-0615B5-4	2	6/15/18	Sure-Grip	Fluid	6/22/18	38130
UAF-B-0615B5-5	2	6/15/18	Sure-Grip	Fluid	6/22/18	39270
UAF-B-0615B5-6	2	6/15/18	Sure-Grip	Fluid	6/22/18	37520
UAF-B-0615B5-7	2	6/15/18	Sure-Grip	Fluid	7/13/18	44840
UAF-B-0615B5-8	2	6/15/18	Sure-Grip	Fluid	7/13/18	44765
UAF-B-0615B5-9	2	6/15/18	Sure-Grip	Fluid	7/13/18	42945
UAF-B-0622B3-1	2	6/22/18	Sure-Grip	Fluid	7/20/18	42300
UAF-B-0622B3-2	2	6/22/18	Sure-Grip	Fluid	7/20/18	42615
UAF-B-0622B3-3	2	6/22/18	Sure-Grip	Fluid	7/20/18	43345
UAF-B-0622B4-1	2	6/22/18	Sure-Grip	Fluid	7/20/18	46630
UAF-B-0622B4-2	2	6/22/18	Sure-Grip	Fluid	7/20/18	44560
UAF-B-0622B4-3	2	6/22/18	Sure-Grip	Fluid	7/20/18	43970
UAF-B-0622B5-1	2	6/22/18	Sure-Grip	Fluid	6/25/18	32980
UAF-B-0622B5-2	2	6/22/18	Sure-Grip	Fluid	6/25/18	32335
UAF-B-0622B5-3	2	6/22/18	Sure-Grip	Fluid	6/25/18	32835
UAF-B-0622B5-4	2	6/22/18	Sure-Grip	Fluid	6/29/18	38305
UAF-B-0622B5-5	2	6/22/18	Sure-Grip	Fluid	6/29/18	37145
UAF-B-0622B5-6	2	6/22/18	Sure-Grip	Fluid	6/29/18	37985
UAF-B-0622B5-7	2	6/22/18	Sure-Grip	Fluid	7/20/18	47020
UAF-B-0622B5-8	2	6/22/18	Sure-Grip	Fluid	7/20/18	45805
UAF-B-0622B5-9	2	6/22/18	Sure-Grip	Fluid	7/20/18	46545
UAF-B-0911-1	2	9/11/18	Sure-Grip	Fluid	9/12/18	25075
UAF-B-0911-2	2	9/11/18	Sure-Grip	Fluid	9/12/18	25020
UAF-B-0911-3	2	9/11/18	Sure-Grip	Fluid	9/12/18	25220
UAF-B-0911-4	2	9/11/18	Sure-Grip	Fluid	9/14/18	31635
UAF-B-0911-5	2	9/11/18	Sure-Grip	Fluid	9/14/18	32930
UAF-B-0911-6	2	9/11/18	Sure-Grip	Fluid	9/14/18	33010

Specimen ID	Round	Cast Date	Grout	Consistency	Test Date	Load (lb)
UAF-B-0911-7	2	9/11/18	Sure-Grip	Fluid	9/12/18	25785
UAF-B-0911-8	2	9/11/18	Sure-Grip	Fluid	9/12/18	25420
UAF-B-0911-9	2	9/11/18	Sure-Grip	Fluid	9/12/18	25500
UAF-B-0911-10	2	9/11/18	Sure-Grip	Fluid	9/14/18	33325
UAF-B-0911-11	2	9/11/18	Sure-Grip	Fluid	9/14/18	31330
UAF-B-0911-12	2	9/11/18	Sure-Grip	Fluid	9/14/18	31980
UAF-B-0911-13	2	9/11/18	Sure-Grip	Fluid	9/18/18	37105
UAF-B-0911-14	2	9/11/18	Sure-Grip	Fluid	9/18/18	36595
UAF-B-0911-15	2	9/11/18	Sure-Grip	Fluid	9/18/18	38010
UAF-B-0911-16	2	9/11/18	Sure-Grip	Fluid	10/9/18	46385
UAF-B-0911-17	2	9/11/18	Sure-Grip	Fluid	10/9/18	47715
UAF-B-0911-18	2	9/11/18	Sure-Grip	Fluid	10/9/18	47490
UAF-B-0911-19	2	9/11/18	Sure-Grip	Fluid	9/18/18	37950
UAF-B-0911-20	2	9/11/18	Sure-Grip	Fluid	9/18/18	35975
UAF-B-0911-21	2	9/11/18	Sure-Grip	Fluid	9/18/18	37440
UAF-B-0911-22	2	9/11/18	Sure-Grip	Fluid	10/9/18	44530
UAF-B-0911-23	2	9/11/18	Sure-Grip	Fluid	10/9/18	44480
UAF-B-0911-24	2	9/11/18	Sure-Grip	Fluid	10/9/18	44675
UAF-B-1113-1	2	11/13/18	Sure-Grip	Flowable	11/14/18	28345
UAF-B-1113-2	2	11/13/18	Sure-Grip	Flowable	11/14/18	27570
UAF-B-1113-3	2	11/13/18	Sure-Grip	Flowable	11/14/18	27750
UAF-B-1113-4	2	11/13/18	Sure-Grip	Flowable	11/16/18	32740
UAF-B-1113-5	2	11/13/18	Sure-Grip	Flowable	11/16/18	33970
UAF-B-1113-6	2	11/13/18	Sure-Grip	Flowable	11/16/18	33355
UAF-B-1113-7	2	11/13/18	Sure-Grip	Flowable	11/14/18	28595
UAF-B-1113-8	2	11/13/18	Sure-Grip	Flowable	11/14/18	28075
UAF-B-1113-9	2	11/13/18	Sure-Grip	Flowable	11/14/18	28470
UAF-B-1113-10	2	11/13/18	Sure-Grip	Flowable	11/16/18	33490
UAF-B-1113-11	2	11/13/18	Sure-Grip	Flowable	11/16/18	31415
UAF-B-1113-12	2	11/13/18	Sure-Grip	Flowable	11/16/18	33365
UAF-B-1113-13	2	11/13/18	Sure-Grip	Flowable	11/20/18	41690
UAF-B-1113-14	2	11/13/18	Sure-Grip	Flowable	11/20/18	41450
UAF-B-1113-15	2	11/13/18	Sure-Grip	Flowable	11/20/18	41495
UAF-B-1113-16	2	11/13/18	Sure-Grip	Flowable	12/11/18	46565
UAF-B-1113-17	2	11/13/18	Sure-Grip	Flowable	12/11/18	46520
UAF-B-1113-18	2	11/13/18	Sure-Grip	Flowable	12/11/18	48490
UAF-B-1113-19	2	11/13/18	Sure-Grip	Flowable	11/20/18	35555
UAF-B-1113-20	2	11/13/18	Sure-Grip	Flowable	11/20/18	36540
UAF-B-1113-21	2	11/13/18	Sure-Grip	Flowable	11/20/18	37780
UAF-B-1113-22	2	11/13/18	Sure-Grip	Flowable	12/11/18	42750
UAF-B-1113-23	2	11/13/18	Sure-Grip	Flowable	12/11/18	42150
UAF-B-1113-24	2	11/13/18	Sure-Grip	Flowable	12/11/18	43260
UAF-0814-D-1	3	8/14/18	Sure-Grip	Fluid	8/15/18	17526
UAF-0814-D-2	3	8/14/18	Sure-Grip	Fluid	8/15/18	17335

Specimen ID	Round	Cast Date	Grout	Consistency	Test Date	Load (lb)
UAF-0814-D-3	3	8/14/18	Sure-Grip	Fluid	8/15/18	17507
UAF-0814-D-4	3	8/14/18	Sure-Grip	Fluid	8/17/18	24158
UAF-0814-D-5	3	8/14/18	Sure-Grip	Fluid	8/17/18	29458
UAF-0814-D-6	3	8/14/18	Sure-Grip	Fluid	8/17/18	31138
UAF-0814-D-7	3	8/14/18	Sure-Grip	Fluid	8/21/18	33205
UAF-0814-D-8	3	8/14/18	Sure-Grip	Fluid	8/21/18	33278
UAF-0814-D-9	3	8/14/18	Sure-Grip	Fluid	8/21/18	31697
UAF-0814-D-10	3	8/14/18	Sure-Grip	Fluid	9/11/18	43545
UAF-0814-D-11	3	8/14/18	Sure-Grip	Fluid	9/11/18	42785
UAF-0814-D-12	3	8/14/18	Sure-Grip	Fluid	9/11/18	40862
UAF-0814-D-C1	3	8/14/18	Sure-Grip	Fluid	8/15/18	56471
UAF-0814-D-C2	3	8/14/18	Sure-Grip	Fluid	8/15/18	56681
UAF-0814-D-C3	3	8/14/18	Sure-Grip	Fluid	8/15/18	57815
UAF-0814-D-C4	3	8/14/18	Sure-Grip	Fluid	8/17/18	72386
UAF-0814-D-C5	3	8/14/18	Sure-Grip	Fluid	8/17/18	80053
UAF-0814-D-C6	3	8/14/18	Sure-Grip	Fluid	8/17/18	82032
UAF-0814-D-C7	3	8/14/18	Sure-Grip	Fluid	8/21/18	82981
UAF-0814-D-C8	3	8/14/18	Sure-Grip	Fluid	8/21/18	86602
UAF-0814-D-C9	3	8/14/18	Sure-Grip	Fluid	8/21/18	82691
UAF-0814-D-C10	3	8/14/18	Sure-Grip	Fluid	9/11/18	87839
UAF-0814-D-C11	3	8/14/18	Sure-Grip	Fluid	9/11/18	106266
UAF-0814-D-C12	3	8/14/18	Sure-Grip	Fluid	9/11/18	104344
UAF-0814-U-1	3	8/14/18	Sure-Grip	Fluid	8/15/18	18690
UAF-0814-U-2	3	8/14/18	Sure-Grip	Fluid	8/15/18	18555
UAF-0814-U-3	3	8/14/18	Sure-Grip	Fluid	8/15/18	18555
UAF-0814-U-4	3	8/14/18	Sure-Grip	Fluid	8/17/18	28135
UAF-0814-U-5	3	8/14/18	Sure-Grip	Fluid	8/17/18	27475
UAF-0814-U-6	3	8/14/18	Sure-Grip	Fluid	8/17/18	29340
UAF-0814-U-7	3	8/14/18	Sure-Grip	Fluid	8/21/18	31180
UAF-0814-U-8	3	8/14/18	Sure-Grip	Fluid	8/21/18	31860
UAF-0814-U-9	3	8/14/18	Sure-Grip	Fluid	8/21/18	32565
UAF-0814-U-10	3	8/14/18	Sure-Grip	Fluid	9/11/18	42165
UAF-0814-U-11	3	8/14/18	Sure-Grip	Fluid	9/11/18	42585
UAF-0814-U-12	3	8/14/18	Sure-Grip	Fluid	9/11/18	41820
UAF-0814-U-C1	3	8/14/18	Sure-Grip	Fluid	8/15/18	56915
UAF-0814-U-C2	3	8/14/18	Sure-Grip	Fluid	8/15/18	53195
UAF-0814-U-C3	3	8/14/18	Sure-Grip	Fluid	8/15/18	53075
UAF-0814-U-C4	3	8/14/18	Sure-Grip	Fluid	8/17/18	80455
UAF-0814-U-C5	3	8/14/18	Sure-Grip	Fluid	8/17/18	70590
UAF-0814-U-C6	3	8/14/18	Sure-Grip	Fluid	8/17/18	68450
UAF-0814-U-C7	3	8/14/18	Sure-Grip	Fluid	8/21/18	93365
UAF-0814-U-C8	3	8/14/18	Sure-Grip	Fluid	8/21/18	89320
UAF-0814-U-C9	3	8/14/18	Sure-Grip	Fluid	8/21/18	77245
UAF-0814-U-C10	3	8/14/18	Sure-Grip	Fluid	9/11/18	109000

Specimen ID	Round	Cast Date	Grout	Consistency	Test Date	Load (lb)
UAF-0814-U-C11	3	8/14/18	Sure-Grip	Fluid	9/11/18	107950
UAF-0814-U-C12	3	8/14/18	Sure-Grip	Fluid	9/11/18	94460
UAF-0821-D-1	3	8/21/18	Sakrete	Flowable	8/22/18	16952
UAF-0821-D-2	3	8/21/18	Sakrete	Flowable	8/22/18	15377
UAF-0821-D-3	3	8/21/18	Sakrete	Flowable	8/22/18	17193
UAF-0821-D-4	3	8/21/18	Sakrete	Flowable	8/24/18	24245
UAF-0821-D-5	3	8/21/18	Sakrete	Flowable	8/24/18	24540
UAF-0821-D-6	3	8/21/18	Sakrete	Flowable	8/24/18	30587
UAF-0821-D-7	3	8/21/18	Sakrete	Flowable	8/28/18	30784
UAF-0821-D-8	3	8/21/18	Sakrete	Flowable	8/28/18	29732
UAF-0821-D-9	3	8/21/18	Sakrete	Flowable	8/28/18	32575
UAF-0821-D-10	3	8/21/18	Sakrete	Flowable	9/18/18	33684
UAF-0821-D-11	3	8/21/18	Sakrete	Flowable	9/18/18	37835
UAF-0821-D-12	3	8/21/18	Sakrete	Flowable	9/18/18	45043
UAF-0821-D-C1	3	8/21/18	Sakrete	Flowable	8/22/18	44297
UAF-0821-D-C2	3	8/21/18	Sakrete	Flowable	8/22/18	40598
UAF-0821-D-C3	3	8/21/18	Sakrete	Flowable	8/22/18	40434
UAF-0821-D-C4	3	8/21/18	Sakrete	Flowable	8/24/18	67224
UAF-0821-D-C5	3	8/21/18	Sakrete	Flowable	8/24/18	67018
UAF-0821-D-C6	3	8/21/18	Sakrete	Flowable	8/24/18	63781
UAF-0821-D-C7	3	8/21/18	Sakrete	Flowable	8/28/18	74788
UAF-0821-D-C8	3	8/21/18	Sakrete	Flowable	8/28/18	84850
UAF-0821-D-C9	3	8/21/18	Sakrete	Flowable	8/28/18	83291
UAF-0821-D-C10	3	8/21/18	Sakrete	Flowable	9/18/18	103761
UAF-0821-D-C11	3	8/21/18	Sakrete	Flowable	9/18/18	104688
UAF-0821-D-C12	3	8/21/18	Sakrete	Flowable	9/18/18	102840
UAF-0821-U-1	3	8/21/18	Sakrete	Flowable	8/22/18	16235
UAF-0821-U-2	3	8/21/18	Sakrete	Flowable	8/22/18	17950
UAF-0821-U-3	3	8/21/18	Sakrete	Flowable	8/22/18	18080
UAF-0821-U-4	3	8/21/18	Sakrete	Flowable	8/24/18	25585
UAF-0821-U-5	3	8/21/18	Sakrete	Flowable	8/24/18	27515
UAF-0821-U-6	3	8/21/18	Sakrete	Flowable	8/24/18	24640
UAF-0821-U-7	3	8/21/18	Sakrete	Flowable	8/28/18	31185
UAF-0821-U-8	3	8/21/18	Sakrete	Flowable	8/28/18	33545
UAF-0821-U-9	3	8/21/18	Sakrete	Flowable	8/28/18	36190
UAF-0821-U-10	3	8/21/18	Sakrete	Flowable	9/18/18	38805
UAF-0821-U-11	3	8/21/18	Sakrete	Flowable	9/18/18	36465
UAF-0821-U-12	3	8/21/18	Sakrete	Flowable	9/18/18	41745
UAF-0821-U-C1	3	8/21/18	Sakrete	Flowable	8/22/18	48110
UAF-0821-U-C2	3	8/21/18	Sakrete	Flowable	8/22/18	44055
UAF-0821-U-C3	3	8/21/18	Sakrete	Flowable	8/22/18	42285
UAF-0821-U-C4	3	8/21/18	Sakrete	Flowable	8/24/18	78590
UAF-0821-U-C5	3	8/21/18	Sakrete	Flowable	8/24/18	76030
UAF-0821-U-C6	3	8/21/18	Sakrete	Flowable	8/24/18	79695

Specimen ID	Round	Cast Date	Grout	Consistency	Test Date	Load (lb)
UAF-0821-U-C7	3	8/21/18	Sakrete	Flowable	8/28/18	90925
UAF-0821-U-C8	3	8/21/18	Sakrete	Flowable	8/28/18	88830
UAF-0821-U-C9	3	8/21/18	Sakrete	Flowable	8/28/18	88325
UAF-0821-U-C10	3	8/21/18	Sakrete	Flowable	9/18/18	109995
UAF-0821-U-C11	3	8/21/18	Sakrete	Flowable	9/18/18	110065
UAF-0821-U-C12	3	8/21/18	Sakrete	Flowable	9/18/18	109500
UAF-0828-D-1	3	8/28/18	Advantage	Dry-Pack	8/29/18	24721
UAF-0828-D-2	3	8/28/18	Advantage	Dry-Pack	8/29/18	22837
UAF-0828-D-3	3	8/28/18	Advantage	Dry-Pack	8/29/18	18260
UAF-0828-D-4	3	8/28/18	Advantage	Dry-Pack	8/31/18	24351
UAF-0828-D-5	3	8/28/18	Advantage	Dry-Pack	8/31/18	24353
UAF-0828-D-6	3	8/28/18	Advantage	Dry-Pack	8/31/18	24270
UAF-0828-D-7	3	8/28/18	Advantage	Dry-Pack	9/4/18	32720
UAF-0828-D-8	3	8/28/18	Advantage	Dry-Pack	9/4/18	33793
UAF-0828-D-9	3	8/28/18	Advantage	Dry-Pack	9/4/18	32839
UAF-0828-D-10	3	8/28/18	Advantage	Dry-Pack	9/25/18	42490
UAF-0828-D-11	3	8/28/18	Advantage	Dry-Pack	9/25/18	39555
UAF-0828-D-12	3	8/28/18	Advantage	Dry-Pack	9/25/18	41484
UAF-0828-D-C1	3	8/28/18	Advantage	Dry-Pack	8/29/18	70357
UAF-0828-D-C2	3	8/28/18	Advantage	Dry-Pack	8/29/18	61864
UAF-0828-D-C3	3	8/28/18	Advantage	Dry-Pack	8/29/18	67615
UAF-0828-D-C4	3	8/28/18	Advantage	Dry-Pack	8/31/18	73240
UAF-0828-D-C5	3	8/28/18	Advantage	Dry-Pack	8/31/18	73239
UAF-0828-D-C6	3	8/28/18	Advantage	Dry-Pack	8/31/18	77844
UAF-0828-D-C7	3	8/28/18	Advantage	Dry-Pack	9/4/18	91259
UAF-0828-D-C8	3	8/28/18	Advantage	Dry-Pack	9/4/18	85660
UAF-0828-D-C9	3	8/28/18	Advantage	Dry-Pack	9/4/18	84309
UAF-0828-D-C10	3	8/28/18	Advantage	Dry-Pack	9/25/18	104025
UAF-0828-D-C11	3	8/28/18	Advantage	Dry-Pack	9/25/18	97058
UAF-0828-D-C12	3	8/28/18	Advantage	Dry-Pack	9/25/18	103731
UAF-0828-U-1	3	8/28/18	Advantage	Dry-Pack	8/29/18	25730
UAF-0828-U-2	3	8/28/18	Advantage	Dry-Pack	8/29/18	26445
UAF-0828-U-3	3	8/28/18	Advantage	Dry-Pack	8/29/18	26045
UAF-0828-U-4	3	8/28/18	Advantage	Dry-Pack	8/31/18	30405
UAF-0828-U-5	3	8/28/18	Advantage	Dry-Pack	8/31/18	26360
UAF-0828-U-6	3	8/28/18	Advantage	Dry-Pack	8/31/18	24315
UAF-0828-U-7	3	8/28/18	Advantage	Dry-Pack	9/4/18	33375
UAF-0828-U-8	3	8/28/18	Advantage	Dry-Pack	9/4/18	33460
UAF-0828-U-9	3	8/28/18	Advantage	Dry-Pack	9/4/18	34180
UAF-0828-U-10	3	8/28/18	Advantage	Dry-Pack	9/25/18	36600
UAF-0828-U-11	3	8/28/18	Advantage	Dry-Pack	9/25/18	38245
UAF-0828-U-12	3	8/28/18	Advantage	Dry-Pack	9/25/18	40320
UAF-0828-U-C1	3	8/28/18	Advantage	Dry-Pack	8/29/18	75380
UAF-0828-U-C2	3	8/28/18	Advantage	Dry-Pack	8/29/18	73210

Specimen ID	Round	Cast Date	Grout	Consistency	Test Date	Load (lb)
UAF-0828-U-C3	3	8/28/18	Advantage	Dry-Pack	8/29/18	80290
UAF-0828-U-C4	3	8/28/18	Advantage	Dry-Pack	8/31/18	90530
UAF-0828-U-C5	3	8/28/18	Advantage	Dry-Pack	8/31/18	85825
UAF-0828-U-C6	3	8/28/18	Advantage	Dry-Pack	8/31/18	86985
UAF-0828-U-C7	3	8/28/18	Advantage	Dry-Pack	9/4/18	92560
UAF-0828-U-C8	3	8/28/18	Advantage	Dry-Pack	9/4/18	74635
UAF-0828-U-C9	3	8/28/18	Advantage	Dry-Pack	9/4/18	99095
UAF-0828-U-C10	3	8/28/18	Advantage	Dry-Pack	9/25/18	112930
UAF-0828-U-C11	3	8/28/18	Advantage	Dry-Pack	9/25/18	112460
UAF-0828-U-C12	3	8/28/18	Advantage	Dry-Pack	9/25/18	111260
UAF-0904-D-1	3	9/4/18	Planigrout	Plastic	9/5/18	21315
UAF-0904-D-2	3	9/4/18	Planigrout	Plastic	9/5/18	22932
UAF-0904-D-3	3	9/4/18	Planigrout	Plastic	9/5/18	24613
UAF-0904-D-4	3	9/4/18	Planigrout	Plastic	9/7/18	30900
UAF-0904-D-5	3	9/4/18	Planigrout	Plastic	9/7/18	30615
UAF-0904-D-6	3	9/4/18	Planigrout	Plastic	9/7/18	30889
UAF-0904-D-7	3	9/4/18	Planigrout	Plastic	9/11/18	38570
UAF-0904-D-8	3	9/4/18	Planigrout	Plastic	9/11/18	39234
UAF-0904-D-9	3	9/4/18	Planigrout	Plastic	9/11/18	35926
UAF-0904-D-10	3	9/4/18	Planigrout	Plastic	10/2/18	49606
UAF-0904-D-11	3	9/4/18	Planigrout	Plastic	10/2/18	46038
UAF-0904-D-12	3	9/4/18	Planigrout	Plastic	10/2/18	49226
UAF-0904-D-C1	3	9/4/18	Planigrout	Plastic	9/5/18	54204
UAF-0904-D-C2	3	9/4/18	Planigrout	Plastic	9/5/18	49680
UAF-0904-D-C3	3	9/4/18	Planigrout	Plastic	9/5/18	46536
UAF-0904-D-C4	3	9/4/18	Planigrout	Plastic	9/7/18	74311
UAF-0904-D-C5	3	9/4/18	Planigrout	Plastic	9/7/18	77386
UAF-0904-D-C6	3	9/4/18	Planigrout	Plastic	9/7/18	73395
UAF-0904-D-C7	3	9/4/18	Planigrout	Plastic	9/11/18	87111
UAF-0904-D-C8	3	9/4/18	Planigrout	Plastic	9/11/18	82238
UAF-0904-D-C9	3	9/4/18	Planigrout	Plastic	9/11/18	84382
UAF-0904-D-C10	3	9/4/18	Planigrout	Plastic	10/2/18	99882
UAF-0904-D-C11	3	9/4/18	Planigrout	Plastic	10/2/18	104448
UAF-0904-D-C12	3	9/4/18	Planigrout	Plastic	10/2/18	102644
UAF-0904-U-1	3	9/4/18	Planigrout	Plastic	9/5/18	22345
UAF-0904-U-2	3	9/4/18	Planigrout	Plastic	9/5/18	22385
UAF-0904-U-3	3	9/4/18	Planigrout	Plastic	9/5/18	22105
UAF-0904-U-4	3	9/4/18	Planigrout	Plastic	9/7/18	29695
UAF-0904-U-5	3	9/4/18	Planigrout	Plastic	9/7/18	31220
UAF-0904-U-6	3	9/4/18	Planigrout	Plastic	9/7/18	32705
UAF-0904-U-7	3	9/4/18	Planigrout	Plastic	9/11/18	38665
UAF-0904-U-8	3	9/4/18	Planigrout	Plastic	9/11/18	38975
UAF-0904-U-9	3	9/4/18	Planigrout	Plastic	9/11/18	38165
UAF-0904-U-10	3	9/4/18	Planigrout	Plastic	10/2/18	47320

Specimen ID	Round	Cast Date	Grout	Consistency	Test Date	Load (lb)
UAF-0904-U-11	3	9/4/18	Planigrout	Plastic	10/2/18	43875
UAF-0904-U-12	3	9/4/18	Planigrout	Plastic	10/2/18	46235
UAF-0904-U-C1	3	9/4/18	Planigrout	Plastic	9/5/18	61935
UAF-0904-U-C2	3	9/4/18	Planigrout	Plastic	9/5/18	70310
UAF-0904-U-C3	3	9/4/18	Planigrout	Plastic	9/5/18	66120
UAF-0904-U-C4	3	9/4/18	Planigrout	Plastic	9/7/18	84820
UAF-0904-U-C5	3	9/4/18	Planigrout	Plastic	9/7/18	85280
UAF-0904-U-C6	3	9/4/18	Planigrout	Plastic	9/7/18	84020
UAF-0904-U-C7	3	9/4/18	Planigrout	Plastic	9/11/18	92950
UAF-0904-U-C8	3	9/4/18	Planigrout	Plastic	9/11/18	90330
UAF-0904-U-C9	3	9/4/18	Planigrout	Plastic	9/11/18	96535
UAF-0904-U-C10	3	9/4/18	Planigrout	Plastic	10/2/18	114840
UAF-0904-U-C11	3	9/4/18	Planigrout	Plastic	10/2/18	119410
UAF-0904-U-C12	3	9/4/18	Planigrout	Plastic	10/2/18	115050
DOT-0925-D-1	3	9/25/18	Sure-Grip	Fluid	9/26/18	18311
DOT-0925-D-2	3	9/25/18	Sure-Grip	Fluid	9/26/18	19105
DOT-0925-D-3	3	9/25/18	Sure-Grip	Fluid	9/26/18	19457
DOT-0925-D-4	3	9/25/18	Sure-Grip	Fluid	9/28/18	26406
DOT-0925-D-5	3	9/25/18	Sure-Grip	Fluid	9/28/18	28428
DOT-0925-D-6	3	9/25/18	Sure-Grip	Fluid	9/28/18	25527
DOT-0925-D-7	3	9/25/18	Sure-Grip	Fluid	10/2/18	34641
DOT-0925-D-8	3	9/25/18	Sure-Grip	Fluid	10/2/18	34379
DOT-0925-D-9	3	9/25/18	Sure-Grip	Fluid	10/2/18	35772
DOT-0925-D-10	3	9/25/18	Sure-Grip	Fluid	10/23/18	32023
DOT-0925-D-11	3	9/25/18	Sure-Grip	Fluid	10/23/18	32313
DOT-0925-D-12	3	9/25/18	Sure-Grip	Fluid	10/23/18	32324
DOT-0925-D-C1	3	9/25/18	Sure-Grip	Fluid	9/26/18	59818
DOT-0925-D-C2	3	9/25/18	Sure-Grip	Fluid	9/26/18	58470
DOT-0925-D-C3	3	9/25/18	Sure-Grip	Fluid	9/26/18	59286
DOT-0925-D-C4	3	9/25/18	Sure-Grip	Fluid	9/28/18	80691
DOT-0925-D-C5	3	9/25/18	Sure-Grip	Fluid	9/28/18	79467
DOT-0925-D-C6	3	9/25/18	Sure-Grip	Fluid	9/28/18	78670
DOT-0925-D-C7	3	9/25/18	Sure-Grip	Fluid	10/2/18	92846
DOT-0925-D-C8	3	9/25/18	Sure-Grip	Fluid	10/2/18	86784
DOT-0925-D-C9	3	9/25/18	Sure-Grip	Fluid	10/2/18	92897
DOT-0925-D-C10	3	9/25/18	Sure-Grip	Fluid	10/23/18	74075
DOT-0925-D-C11	3	9/25/18	Sure-Grip	Fluid	10/23/18	76651
DOT-0925-D-C12	3	9/25/18	Sure-Grip	Fluid	10/23/18	69092
DOT-0925-U-1	3	9/25/18	Sure-Grip	Fluid	9/26/18	14410
DOT-0925-U-2	3	9/25/18	Sure-Grip	Fluid	9/26/18	15165
DOT-0925-U-3	3	9/25/18	Sure-Grip	Fluid	9/26/18	14925
DOT-0925-U-4	3	9/25/18	Sure-Grip	Fluid	9/28/18	27720
DOT-0925-U-5	3	9/25/18	Sure-Grip	Fluid	9/28/18	30630
DOT-0925-U-6	3	9/25/18	Sure-Grip	Fluid	9/28/18	29625

Specimen ID	Round	Cast Date	Grout	Consistency	Test Date	Load (lb)
DOT-0925-U-7	3	9/25/18	Sure-Grip	Fluid	10/2/18	32770
DOT-0925-U-8	3	9/25/18	Sure-Grip	Fluid	10/2/18	33120
DOT-0925-U-9	3	9/25/18	Sure-Grip	Fluid	10/2/18	33955
DOT-0925-U-10	3	9/25/18	Sure-Grip	Fluid	10/23/18	43915
DOT-0925-U-11	3	9/25/18	Sure-Grip	Fluid	10/23/18	43970
DOT-0925-U-12	3	9/25/18	Sure-Grip	Fluid	10/23/18	42010
DOT-0925-U-C1	3	9/25/18	Sure-Grip	Fluid	9/26/18	63145
DOT-0925-U-C2	3	9/25/18	Sure-Grip	Fluid	9/26/18	59655
DOT-0925-U-C3	3	9/25/18	Sure-Grip	Fluid	9/26/18	60200
DOT-0925-U-C4	3	9/25/18	Sure-Grip	Fluid	9/28/18	84810
DOT-0925-U-C5	3	9/25/18	Sure-Grip	Fluid	9/28/18	67155
DOT-0925-U-C6	3	9/25/18	Sure-Grip	Fluid	9/28/18	84605
DOT-0925-U-C7	3	9/25/18	Sure-Grip	Fluid	10/2/18	93245
DOT-0925-U-C8	3	9/25/18	Sure-Grip	Fluid	10/2/18	93790
DOT-0925-U-C9	3	9/25/18	Sure-Grip	Fluid	10/2/18	95680
DOT-0925-U-C10	3	9/25/18	Sure-Grip	Fluid	10/23/18	114465
DOT-0925-U-C11	3	9/25/18	Sure-Grip	Fluid	10/23/18	110220
DOT-0925-U-C12	3	9/25/18	Sure-Grip	Fluid	10/23/18	118190
DOT-1002-D-1	3	10/2/18	Sakrete	Flowable	10/3/18	21434
DOT-1002-D-2	3	10/2/18	Sakrete	Flowable	10/3/18	19299
DOT-1002-D-3	3	10/2/18	Sakrete	Flowable	10/3/18	19981
DOT-1002-D-4	3	10/2/18	Sakrete	Flowable	10/5/18	31686
DOT-1002-D-5	3	10/2/18	Sakrete	Flowable	10/5/18	35115
DOT-1002-D-6	3	10/2/18	Sakrete	Flowable	10/5/18	36050
DOT-1002-D-7	3	10/2/18	Sakrete	Flowable	10/9/18	38138
DOT-1002-D-8	3	10/2/18	Sakrete	Flowable	10/9/18	40573
DOT-1002-D-9	3	10/2/18	Sakrete	Flowable	10/9/18	40096
DOT-1002-D-10	3	10/2/18	Sakrete	Flowable	10/30/18	49824
DOT-1002-D-11	3	10/2/18	Sakrete	Flowable	10/30/18	47951
DOT-1002-D-12	3	10/2/18	Sakrete	Flowable	10/30/18	48366
DOT-1002-D-C1	3	10/2/18	Sakrete	Flowable	10/3/18	51059
DOT-1002-D-C2	3	10/2/18	Sakrete	Flowable	10/3/18	50000
DOT-1002-D-C3	3	10/2/18	Sakrete	Flowable	10/3/18	51804
DOT-1002-D-C4	3	10/2/18	Sakrete	Flowable	10/5/18	83285
DOT-1002-D-C5	3	10/2/18	Sakrete	Flowable	10/5/18	78837
DOT-1002-D-C6	3	10/2/18	Sakrete	Flowable	10/5/18	80336
DOT-1002-D-C7	3	10/2/18	Sakrete	Flowable	10/9/18	100047
DOT-1002-D-C8	3	10/2/18	Sakrete	Flowable	10/9/18	89786
DOT-1002-D-C9	3	10/2/18	Sakrete	Flowable	10/9/18	87012
DOT-1002-D-C10	3	10/2/18	Sakrete	Flowable	10/30/18	112197
DOT-1002-D-C11	3	10/2/18	Sakrete	Flowable	10/30/18	115475
DOT-1002-D-C12	3	10/2/18	Sakrete	Flowable	10/30/18	107865
DOT-1002-U-1	3	10/2/18	Sakrete	Flowable	10/3/18	17840
DOT-1002-U-2	3	10/2/18	Sakrete	Flowable	10/3/18	18190

Specimen ID	Round	Cast Date	Grout	Consistency	Test Date	Load (lb)
DOT-1002-U-3	3	10/2/18	Sakrete	Flowable	10/3/18	16070
DOT-1002-U-4	3	10/2/18	Sakrete	Flowable	10/5/18	33460
DOT-1002-U-5	3	10/2/18	Sakrete	Flowable	10/5/18	34940
DOT-1002-U-6	3	10/2/18	Sakrete	Flowable	10/5/18	33520
DOT-1002-U-7	3	10/2/18	Sakrete	Flowable	10/9/18	40160
DOT-1002-U-8	3	10/2/18	Sakrete	Flowable	10/9/18	39335
DOT-1002-U-9	3	10/2/18	Sakrete	Flowable	10/9/18	38295
DOT-1002-U-10	3	10/2/18	Sakrete	Flowable	10/30/18	41410
DOT-1002-U-11	3	10/2/18	Sakrete	Flowable	10/30/18	45120
DOT-1002-U-12	3	10/2/18	Sakrete	Flowable	10/30/18	45190
DOT-1002-U-C1	3	10/2/18	Sakrete	Flowable	10/3/18	49350
DOT-1002-U-C2	3	10/2/18	Sakrete	Flowable	10/3/18	48220
DOT-1002-U-C3	3	10/2/18	Sakrete	Flowable	10/3/18	31440
DOT-1002-U-C4	3	10/2/18	Sakrete	Flowable	10/5/18	84645
DOT-1002-U-C5	3	10/2/18	Sakrete	Flowable	10/5/18	79020
DOT-1002-U-C6	3	10/2/18	Sakrete	Flowable	10/5/18	87135
DOT-1002-U-C7	3	10/2/18	Sakrete	Flowable	10/9/18	102425
DOT-1002-U-C8	3	10/2/18	Sakrete	Flowable	10/9/18	91160
DOT-1002-U-C9	3	10/2/18	Sakrete	Flowable	10/9/18	95090
DOT-1002-U-C10	3	10/2/18	Sakrete	Flowable	10/30/18	111515
DOT-1002-U-C11	3	10/2/18	Sakrete	Flowable	10/30/18	118095
DOT-1002-U-C12	3	10/2/18	Sakrete	Flowable	10/30/18	116160
UAF-1016-D-1	3	10/16/18	Masterflow	Plastic	10/17/18	19913
UAF-1016-D-2	3	10/16/18	Masterflow	Plastic	10/17/18	19935
UAF-1016-D-3	3	10/16/18	Masterflow	Plastic	10/17/18	21800
UAF-1016-D-4	3	10/16/18	Masterflow	Plastic	10/19/18	10939
UAF-1016-D-5	3	10/16/18	Masterflow	Plastic	10/19/18	12519
UAF-1016-D-6	3	10/16/18	Masterflow	Plastic	10/19/18	15783
UAF-1016-D-7	3	10/16/18	Masterflow	Plastic	10/23/18	32799
UAF-1016-D-8	3	10/16/18	Masterflow	Plastic	10/23/18	33543
UAF-1016-D-9	3	10/16/18	Masterflow	Plastic	10/23/18	31086
UAF-1016-D-10	3	10/16/18	Masterflow	Plastic	11/13/18	48865
UAF-1016-D-11	3	10/16/18	Masterflow	Plastic	11/13/18	47875
UAF-1016-D-12	3	10/16/18	Masterflow	Plastic	11/13/18	47826
UAF-1016-D-C1	3	10/16/18	Masterflow	Plastic	10/17/18	50870
UAF-1016-D-C2	3	10/16/18	Masterflow	Plastic	10/17/18	37154
UAF-1016-D-C3	3	10/16/18	Masterflow	Plastic	10/17/18	35233
UAF-1016-D-C4	3	10/16/18	Masterflow	Plastic	10/19/18	47831
UAF-1016-D-C5	3	10/16/18	Masterflow	Plastic	10/19/18	52727
UAF-1016-D-C6	3	10/16/18	Masterflow	Plastic	10/19/18	53864
UAF-1016-D-C7	3	10/16/18	Masterflow	Plastic	10/23/18	73737
UAF-1016-D-C8	3	10/16/18	Masterflow	Plastic	10/23/18	61416
UAF-1016-D-C9	3	10/16/18	Masterflow	Plastic	10/23/18	63100
UAF-1016-D-C10	3	10/16/18	Masterflow	Plastic	11/13/18	117759

Specimen ID	Round	Cast Date	Grout	Consistency	Test Date	Load (lb)
UAF-1016-D-C11	3	10/16/18	Masterflow	Plastic	11/13/18	112839
UAF-1016-D-C12	3	10/16/18	Masterflow	Plastic	11/13/18	113833
UAF-1016-U-1	3	10/16/18	Masterflow	Plastic	10/17/18	18210
UAF-1016-U-2	3	10/16/18	Masterflow	Plastic	10/17/18	18425
UAF-1016-U-3	3	10/16/18	Masterflow	Plastic	10/17/18	19695
UAF-1016-U-4	3	10/16/18	Masterflow	Plastic	10/19/18	27160
UAF-1016-U-5	3	10/16/18	Masterflow	Plastic	10/19/18	28665
UAF-1016-U-6	3	10/16/18	Masterflow	Plastic	10/19/18	32470
UAF-1016-U-7	3	10/16/18	Masterflow	Plastic	10/23/18	36985
UAF-1016-U-8	3	10/16/18	Masterflow	Plastic	10/23/18	39045
UAF-1016-U-9	3	10/16/18	Masterflow	Plastic	10/23/18	37300
UAF-1016-U-10	3	10/16/18	Masterflow	Plastic	11/13/18	50000
UAF-1016-U-11	3	10/16/18	Masterflow	Plastic	11/13/18	49435
UAF-1016-U-12	3	10/16/18	Masterflow	Plastic	11/13/18	47560
UAF-1016-U-C1	3	10/16/18	Masterflow	Plastic	10/17/18	37590
UAF-1016-U-C2	3	10/16/18	Masterflow	Plastic	10/17/18	44960
UAF-1016-U-C3	3	10/16/18	Masterflow	Plastic	10/17/18	43620
UAF-1016-U-C4	3	10/16/18	Masterflow	Plastic	10/19/18	62465
UAF-1016-U-C5	3	10/16/18	Masterflow	Plastic	10/19/18	45795
UAF-1016-U-C6	3	10/16/18	Masterflow	Plastic	10/19/18	54935
UAF-1016-U-C7	3	10/16/18	Masterflow	Plastic	10/23/18	53770
UAF-1016-U-C8	3	10/16/18	Masterflow	Plastic	10/23/18	41670
UAF-1016-U-C9	3	10/16/18	Masterflow	Plastic	10/23/18	60940
UAF-1016-U-C10	3	10/16/18	Masterflow	Plastic	11/13/18	81420
UAF-1016-U-C11	3	10/16/18	Masterflow	Plastic	11/13/18	52560
UAF-1016-U-C12	3	10/16/18	Masterflow	Plastic	11/13/18	55335
UAF-1121-1	4	11/21/18	Sure-Grip	Fluid	11/24/18	33110
UAF-1121-2	4	11/21/18	Sure-Grip	Fluid	11/24/18	35285
UAF-1121-3	4	11/21/18	Sure-Grip	Fluid	11/24/18	31825
UAF-1121-4	4	11/21/18	Sure-Grip	Fluid	11/28/18	38070
UAF-1121-5	4	11/21/18	Sure-Grip	Fluid	11/28/18	37885
UAF-1121-6	4	11/21/18	Sure-Grip	Fluid	11/28/18	38995
UAF-1121-7	4	11/21/18	Sure-Grip	Fluid	12/19/18	43765
UAF-1121-8	4	11/21/18	Sure-Grip	Fluid	12/19/18	46650
UAF-1121-9	4	11/21/18	Sure-Grip	Fluid	12/19/18	44885
UAF-1121-R1	4	11/21/18	Sure-Grip	Fluid	12/19/18	47770
UAF-1121-R2	4	11/21/18	Sure-Grip	Fluid	12/19/18	46445
UAF-1121-R3	4	11/21/18	Sure-Grip	Fluid	12/19/18	44365
UAF-1128-1	4	11/28/18	Sure-Grip	Fluid	12/1/18	32065
UAF-1128-2	4	11/28/18	Sure-Grip	Fluid	12/1/18	29540
UAF-1128-3	4	11/28/18	Sure-Grip	Fluid	12/1/18	27575
UAF-1128-4	4	11/28/18	Sure-Grip	Fluid	12/5/18	34840
UAF-1128-5	4	11/28/18	Sure-Grip	Fluid	12/5/18	35065
UAF-1128-6	4	11/28/18	Sure-Grip	Fluid	12/5/18	34660

Specimen ID	Round	Cast Date	Grout	Consistency	Test Date	Load (lb)
UAF-1128-7	4	11/28/18	Sure-Grip	Fluid	12/26/18	41825
UAF-1128-8	4	11/28/18	Sure-Grip	Fluid	12/26/18	37555
UAF-1128-9	4	11/28/18	Sure-Grip	Fluid	12/26/18	34955
UAF-1128-R1	4	11/28/18	Sure-Grip	Fluid	12/26/18	43120
UAF-1128-R2	4	11/28/18	Sure-Grip	Fluid	12/26/18	43570
UAF-1128-R3	4	11/28/18	Sure-Grip	Fluid	12/26/18	44350
UAF-1205-1	4	12/5/18	Sure-Grip	Fluid	12/8/18	31375
UAF-1205-2	4	12/5/18	Sure-Grip	Fluid	12/8/18	30620
UAF-1205-3	4	12/5/18	Sure-Grip	Fluid	12/8/18	30245
UAF-1205-4	4	12/5/18	Sure-Grip	Fluid	12/12/18	36020
UAF-1205-5	4	12/5/18	Sure-Grip	Fluid	12/12/18	33200
UAF-1205-6	4	12/5/18	Sure-Grip	Fluid	12/12/18	35480
UAF-1205-7	4	12/5/18	Sure-Grip	Fluid	1/2/19	41545
UAF-1205-8	4	12/5/18	Sure-Grip	Fluid	1/2/19	37990
UAF-1205-9	4	12/5/18	Sure-Grip	Fluid	1/2/19	42495
UAF-1205-R1	4	12/5/18	Sure-Grip	Fluid	1/2/19	42995
UAF-1205-R2	4	12/5/18	Sure-Grip	Fluid	1/2/19	41715
UAF-1205-R3	4	12/5/18	Sure-Grip	Fluid	1/2/19	43500
UAF-0218-A1	4	2/18/19	Sure-Grip	Fluid	2/21/19	28230
UAF-0218-A2	4	2/18/19	Sure-Grip	Fluid	2/21/19	28015
UAF-0218-A3	4	2/18/19	Sure-Grip	Fluid	2/21/19	28170
UAF-0218-A4	4	2/18/19	Sure-Grip	Fluid	2/25/19	34325
UAF-0218-A5	4	2/18/19	Sure-Grip	Fluid	2/25/19	33980
UAF-0218-A6	4	2/18/19	Sure-Grip	Fluid	2/25/19	34865
UAF-0218-A7	4	2/18/19	Sure-Grip	Fluid	3/18/19	43790
UAF-0218-A8	4	2/18/19	Sure-Grip	Fluid	3/18/19	44055
UAF-0218-A9	4	2/18/19	Sure-Grip	Fluid	3/18/19	43605
UAF-0218-A10	4	2/18/19	Sure-Grip	Fluid	3/18/19	42710
UAF-0218-A11	4	2/18/19	Sure-Grip	Fluid	3/18/19	43930
UAF-0218-A12	4	2/18/19	Sure-Grip	Fluid	3/18/19	43665
UAF-0218-B1	4	2/18/19	Sure-Grip	Fluid	2/21/19	27255
UAF-0218-B2	4	2/18/19	Sure-Grip	Fluid	2/21/19	26900
UAF-0218-B3	4	2/18/19	Sure-Grip	Fluid	2/21/19	27460
UAF-0218-B4	4	2/18/19	Sure-Grip	Fluid	2/25/19	34230
UAF-0218-B5	4	2/18/19	Sure-Grip	Fluid	2/25/19	33960
UAF-0218-B6	4	2/18/19	Sure-Grip	Fluid	2/25/19	34060
UAF-0218-B7	4	2/18/19	Sure-Grip	Fluid	3/18/19	39935
UAF-0218-B8	4	2/18/19	Sure-Grip	Fluid	3/18/19	41360
UAF-0218-B9	4	2/18/19	Sure-Grip	Fluid	3/18/19	42365
UAF-0218-B10	4	2/18/19	Sure-Grip	Fluid	3/18/19	44200
UAF-0218-B11	4	2/18/19	Sure-Grip	Fluid	3/18/19	42715
UAF-0218-B12	4	2/18/19	Sure-Grip	Fluid	3/18/19	41560
UAF-0319-A1	4	3/19/19	Sure-Grip	Fluid	3/20/19	23580
UAF-0319-A2	4	3/19/19	Sure-Grip	Fluid	3/20/19	22415

Specimen ID	Round	Cast Date	Grout	Consistency	Test Date	Load (lb)
UAF-0319-A3	4	3/19/19	Sure-Grip	Fluid	3/20/19	22240
UAF-0319-A4	4	3/19/19	Sure-Grip	Fluid	3/22/19	29895
UAF-0319-A5	4	3/19/19	Sure-Grip	Fluid	3/22/19	29200
UAF-0319-A6	4	3/19/19	Sure-Grip	Fluid	3/22/19	30245
UAF-0319-A7	4	3/19/19	Sure-Grip	Fluid	3/26/19	37865
UAF-0319-A8	4	3/19/19	Sure-Grip	Fluid	3/26/19	37040
UAF-0319-A9	4	3/19/19	Sure-Grip	Fluid	3/26/19	36715
UAF-0319-A10	4	3/19/19	Sure-Grip	Fluid	4/16/19	45755
UAF-0319-A11	4	3/19/19	Sure-Grip	Fluid	4/16/19	45700
UAF-0319-A12	4	3/19/19	Sure-Grip	Fluid	4/16/19	46685
UAF-0319-B1	4	3/19/19	Sure-Grip	Fluid	3/20/19	20870
UAF-0319-B2	4	3/19/19	Sure-Grip	Fluid	3/20/19	20695
UAF-0319-B3	4	3/19/19	Sure-Grip	Fluid	3/20/19	20690
UAF-0319-B4	4	3/19/19	Sure-Grip	Fluid	3/22/19	28620
UAF-0319-B5	4	3/19/19	Sure-Grip	Fluid	3/22/19	28455
UAF-0319-B6	4	3/19/19	Sure-Grip	Fluid	3/22/19	28365
UAF-0319-B7	4	3/19/19	Sure-Grip	Fluid	3/26/19	34260
UAF-0319-B8	4	3/19/19	Sure-Grip	Fluid	3/26/19	34885
UAF-0319-B9	4	3/19/19	Sure-Grip	Fluid	3/26/19	34700
UAF-0319-B10	4	3/19/19	Sure-Grip	Fluid	4/16/19	45220
UAF-0319-B11	4	3/19/19	Sure-Grip	Fluid	4/16/19	43680
UAF-0319-B12	4	3/19/19	Sure-Grip	Fluid	4/16/19	39015
UAF-0321-A1	4	3/21/19	Sure-Grip	Fluid	3/22/19	23600
UAF-0321-A2	4	3/21/19	Sure-Grip	Fluid	3/22/19	22345
UAF-0321-A3	4	3/21/19	Sure-Grip	Fluid	3/22/19	22195
UAF-0321-A4	4	3/21/19	Sure-Grip	Fluid	3/24/19	34435
UAF-0321-A5	4	3/21/19	Sure-Grip	Fluid	3/24/19	34545
UAF-0321-A6	4	3/21/19	Sure-Grip	Fluid	3/24/19	32885
UAF-0321-A7	4	3/21/19	Sure-Grip	Fluid	3/28/19	38340
UAF-0321-A8	4	3/21/19	Sure-Grip	Fluid	3/28/19	37980
UAF-0321-A9	4	3/21/19	Sure-Grip	Fluid	3/28/19	37315
UAF-0321-A10	4	3/21/19	Sure-Grip	Fluid	4/18/19	46295
UAF-0321-A11	4	3/21/19	Sure-Grip	Fluid	4/18/19	46740
UAF-0321-A12	4	3/21/19	Sure-Grip	Fluid	4/18/19	45005
UAF-0321-B1	4	3/21/19	Sure-Grip	Fluid	3/22/19	23390
UAF-0321-B2	4	3/21/19	Sure-Grip	Fluid	3/22/19	23140
UAF-0321-B3	4	3/21/19	Sure-Grip	Fluid	3/22/19	23460
UAF-0321-B4	4	3/21/19	Sure-Grip	Fluid	3/24/19	33100
UAF-0321-B5	4	3/21/19	Sure-Grip	Fluid	3/24/19	32190
UAF-0321-B6	4	3/21/19	Sure-Grip	Fluid	3/24/19	32310
UAF-0321-B7	4	3/21/19	Sure-Grip	Fluid	3/28/19	37505
UAF-0321-B8	4	3/21/19	Sure-Grip	Fluid	3/28/19	36915
UAF-0321-B9	4	3/21/19	Sure-Grip	Fluid	3/28/19	38010
UAF-0321-B10	4	3/21/19	Sure-Grip	Fluid	4/18/19	46425

Specimen ID	Round	Cast Date	Grout	Consistency	Test Date	Load (lb)
UAF-0321-B11	4	3/21/19	Sure-Grip	Fluid	4/18/19	47425
UAF-0321-B12	4	3/21/19	Sure-Grip	Fluid	4/18/19	45600
UAF-0415-A1	4	4/15/19	Sakrete	Flowable	4/16/19	17850
UAF-0415-A2	4	4/15/19	Sakrete	Flowable	4/16/19	18205
UAF-0415-A3	4	4/15/19	Sakrete	Flowable	4/16/19	19115
UAF-0415-A4	4	4/15/19	Sakrete	Flowable	4/18/19	28820
UAF-0415-A5	4	4/15/19	Sakrete	Flowable	4/18/19	28025
UAF-0415-A6	4	4/15/19	Sakrete	Flowable	4/18/19	26130
UAF-0415-A7	4	4/15/19	Sakrete	Flowable	4/22/19	35635
UAF-0415-A8	4	4/15/19	Sakrete	Flowable	4/22/19	32595
UAF-0415-A9	4	4/15/19	Sakrete	Flowable	4/22/19	36080
UAF-0415-A10	4	4/15/19	Sakrete	Flowable	5/13/19	43505
UAF-0415-A11	4	4/15/19	Sakrete	Flowable	5/13/19	43095
UAF-0415-A12	4	4/15/19	Sakrete	Flowable	5/13/19	44515
UAF-0415-B1	4	4/15/19	Sakrete	Flowable	4/16/19	17480
UAF-0415-B2	4	4/15/19	Sakrete	Flowable	4/16/19	17325
UAF-0415-B3	4	4/15/19	Sakrete	Flowable	4/16/19	16715
UAF-0415-B4	4	4/15/19	Sakrete	Flowable	4/18/19	29330
UAF-0415-B5	4	4/15/19	Sakrete	Flowable	4/18/19	29460
UAF-0415-B6	4	4/15/19	Sakrete	Flowable	4/18/19	31390
UAF-0415-B7	4	4/15/19	Sakrete	Flowable	4/22/19	37765
UAF-0415-B8	4	4/15/19	Sakrete	Flowable	4/22/19	37895
UAF-0415-B9	4	4/15/19	Sakrete	Flowable	4/22/19	37875
UAF-0415-B10	4	4/15/19	Sakrete	Flowable	5/13/19	43155
UAF-0415-B11	4	4/15/19	Sakrete	Flowable	5/13/19	43685
UAF-0415-B12	4	4/15/19	Sakrete	Flowable	5/13/19	43795
UAF-0422-A1	4	4/22/19	Sakrete	Flowable	4/25/19	31195
UAF-0422-A2	4	4/22/19	Sakrete	Flowable	4/25/19	31600
UAF-0422-A3	4	4/22/19	Sakrete	Flowable	4/25/19	31620
UAF-0422-A4	4	4/22/19	Sakrete	Flowable	4/29/19	37690
UAF-0422-A5	4	4/22/19	Sakrete	Flowable	4/29/19	37655
UAF-0422-A6	4	4/22/19	Sakrete	Flowable	4/29/19	37865
UAF-0422-A7	4	4/22/19	Sakrete	Flowable	5/20/19	43435
UAF-0422-A8	4	4/22/19	Sakrete	Flowable	5/20/19	41860
UAF-0422-A9	4	4/22/19	Sakrete	Flowable	5/20/19	43450
UAF-0422-A10	4	4/22/19	Sakrete	Flowable	5/20/19	42940
UAF-0422-A11	4	4/22/19	Sakrete	Flowable	5/20/19	43925
UAF-0422-A12	4	4/22/19	Sakrete	Flowable	5/20/19	41385
UAF-0422-B1	4	4/22/19	Sakrete	Flowable	4/25/19	32500
UAF-0422-B2	4	4/22/19	Sakrete	Flowable	4/25/19	31240
UAF-0422-B3	4	4/22/19	Sakrete	Flowable	4/25/19	31680
UAF-0422-B4	4	4/22/19	Sakrete	Flowable	4/29/19	37940
UAF-0422-B5	4	4/22/19	Sakrete	Flowable	4/29/19	36900
UAF-0422-B6	4	4/22/19	Sakrete	Flowable	4/29/19	39055

Specimen ID	Round	Cast Date	Grout	Consistency	Test Date	Load (lb)
UAF-0422-B7	4	4/22/19	Sakrete	Flowable	5/20/19	42125
UAF-0422-B8	4	4/22/19	Sakrete	Flowable	5/20/19	41635
UAF-0422-B9	4	4/22/19	Sakrete	Flowable	5/20/19	41155
UAF-0422-B10	4	4/22/19	Sakrete	Flowable	5/20/19	43225
UAF-0422-B11	4	4/22/19	Sakrete	Flowable	5/20/19	41755
UAF-0422-B12	4	4/22/19	Sakrete	Flowable	5/20/19	43260
PPC-0604-A1	5	6/4/19	PPC		6/7/2019	25480
PPC-0604-A2	5	6/4/19	PPC		6/7/2019	24375
PPC-0604-A3	5	6/4/19	PPC		6/7/2019	25050
PPC-0604-A4	5	6/4/19	PPC		6/11/2019	22290
PPC-0604-A5	5	6/4/19	PPC		6/11/2019	24395
PPC-0604-A6	5	6/4/19	PPC		6/11/2019	23135
PPC-0604-B1	5	6/4/19	PPC		6/7/2019	24555
PPC-0604-B2	5	6/4/19	PPC		6/7/2019	24130
PPC-0604-B3	5	6/4/19	PPC		6/7/2019	23605
PPC-0604-B4	5	6/4/19	PPC		6/11/2019	25400
PPC-0604-B5	5	6/4/19	PPC		6/11/2019	25195
PPC-0604-B6	5	6/4/19	PPC		6/11/2019	24940
PPC-0604-C-A1	5	6/4/19	PPC		6/7/2019	73425
PPC-0604-C-A2	5	6/4/19	PPC		6/7/2019	72060
PPC-0604-C-A3	5	6/4/19	PPC		6/7/2019	70650
PPC-0604-C-A4	5	6/4/19	PPC		6/11/2019	77560
PPC-0604-C-A5	5	6/4/19	PPC		6/11/2019	77515
PPC-0604-C-A6	5	6/4/19	PPC		6/11/2019	70220
PPC-0604-C-B1	5	6/4/19	PPC		6/7/2019	70890
PPC-0604-C-B2	5	6/4/19	PPC		6/7/2019	71505
PPC-0604-C-B3	5	6/4/19	PPC		6/7/2019	69930
PPC-0604-C-B4	5	6/4/19	PPC		6/11/2019	75385
PPC-0604-C-B5	5	6/4/19	PPC		6/11/2019	74470
PPC-0604-C-B6	5	6/4/19	PPC		6/11/2019	74150
PPC-0604-S-A1	5	6/4/19	PPC		6/11/2019	71420
PPC-0604-S-A2	5	6/4/19	PPC		6/11/2019	75225
PPC-0604-S-A3	5	6/4/19	PPC		6/11/2019	57800
PPC-0604-S-B1	5	6/4/19	PPC		6/11/2019	84990
PPC-0604-S-B2	5	6/4/19	PPC		6/11/2019	49365
PPC-0604-S-B3	5	6/4/19	PPC		6/11/2019	64695
PPC-0604-A7	5	6/4/19	PPC		7/2/19	26740
PPC-0604-A8	5	6/4/19	PPC		7/2/19	24450
PPC-0604-A9	5	6/4/19	PPC		7/2/19	26250
PPC-0604-A10	5	6/4/19	PPC		7/2/19	26860
PPC-0604-A11	5	6/4/19	PPC		7/2/19	27250
PPC-0604-A12	5	6/4/19	PPC		7/2/19	27360
PPC-0604-B7	5	6/4/19	PPC		7/2/19	24545
PPC-0604-B8	5	6/4/19	PPC		7/2/19	20270

Specimen ID	Round	Cast Date	Grout	Consistency	Test Date	Load (lb)
PPC-0604-B9	5	6/4/19	PPC		7/2/19	23010
PPC-0604-B10	5	6/4/19	PPC		7/2/19	25360
PPC-0604-B11	5	6/4/19	PPC		7/2/19	25635
PPC-0604-B12	5	6/4/19	PPC		7/2/19	25025
PPC-0604-C-A7	5	6/4/19	PPC		7/2/19	74665
PPC-0604-C-A8	5	6/4/19	PPC		7/2/19	74815
PPC-0604-C-A9	5	6/4/19	PPC		7/2/19	73790
PPC-0604-C-B7	5	6/4/19	PPC		7/2/19	78100
PPC-0604-C-B8	5	6/4/19	PPC		7/2/19	79485
PPC-0604-C-B9	5	6/4/19	PPC		7/2/19	75170
PPC-0604-S-A4	5	6/4/19	PPC		7/2/19	57530
PPC-0604-S-A5	5	6/4/19	PPC		7/2/19	67085
PPC-0604-S-A6	5	6/4/19	PPC		7/2/19	57755
PPC-0604-S-A7	5	6/4/19	PPC		7/2/19	137185
PPC-0604-S-A8	5	6/4/19	PPC		7/2/19	121150
PPC-0604-S-A9	5	6/4/19	PPC		7/2/19	115610
PPC-0604-S-B4	5	6/4/19	PPC		7/2/19	74330
PPC-0604-S-B5	5	6/4/19	PPC		7/2/19	68210
PPC-0604-S-B6	5	6/4/19	PPC		7/2/19	64635
PPC-0604-S-B7	5	6/4/19	PPC		7/2/19	133165
PPC-0604-S-B8	5	6/4/19	PPC		7/2/19	100140
PPC-0604-S-B9	5	6/4/19	PPC		7/2/19	113380

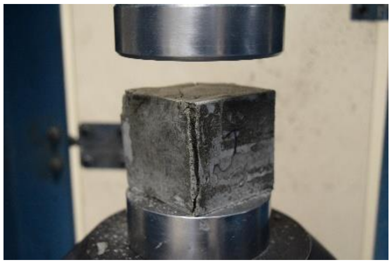
APPENDIX E.

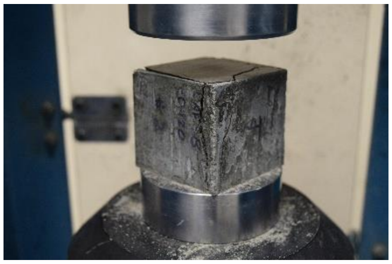
PHOTOS OF SPECIMENS DURING STRENGTH TEST

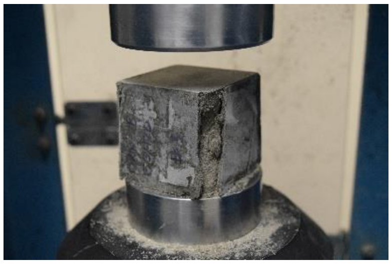
E.1 Round 1

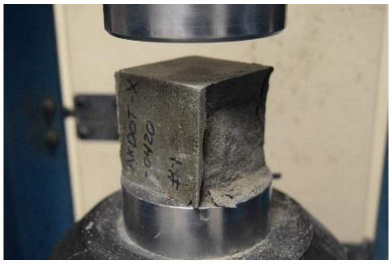
E.1.1 Round 1 Batch 042018

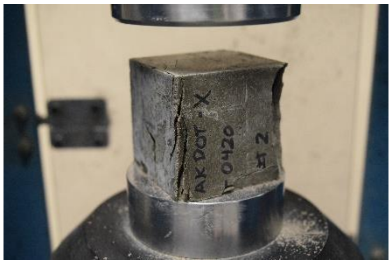
E.1.1.1 7-Day Test (04/27/2018)

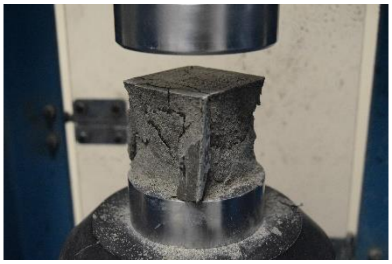

UAF-B-0420-1

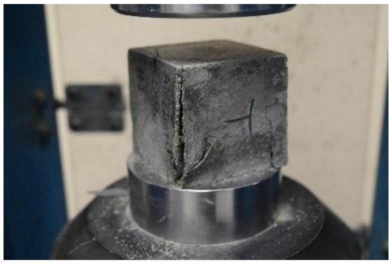

UAF-B-0420-2

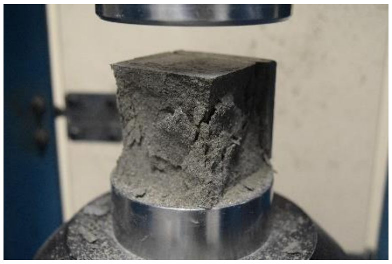

UAF-B-0420-3

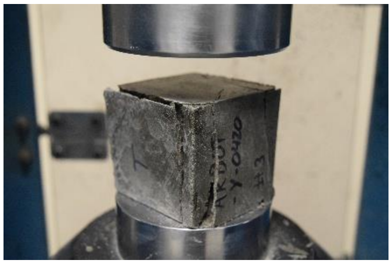

AKDOT-X-0420-1


AKDOT-X-0420-2

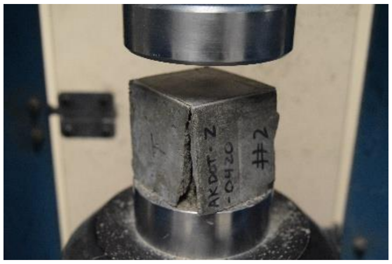

AKDOT-X-0420-3

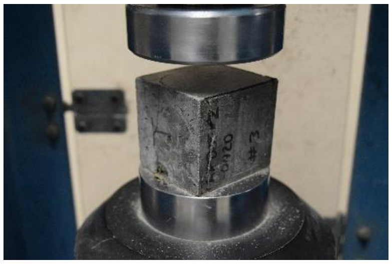

AKDOT-Y-0420-1


AKDOT-Y-0420-2


AKDOT-Y-0420-3


AKDOT-Z-0420-1


AKDOT-Z-0420-2


AKDOT-Z-0420-3

E.1.1.2 28-Day Test (05/18/2018)


UAF-B-0420-4

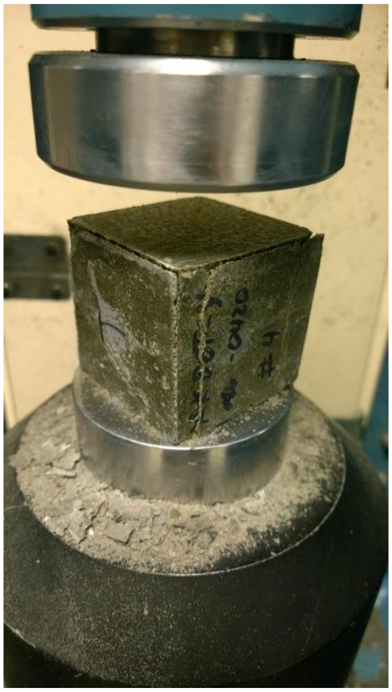

UAF-B-0420-5


UAF-B-0420-6


AKDOT-X-0420-4


AKDOT-X-0420-5


AKDOT-X-0420-6


AKDOT-Y-0420-4


AKDOT-Y-0420-5


AKDOT-Y-0420-6

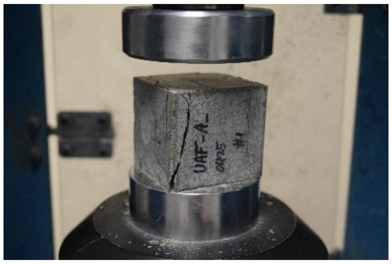

AKDOT-Z-0420-4

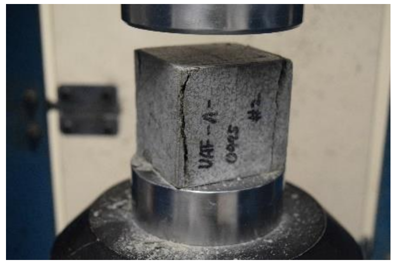

AKDOT-Z-0420-5

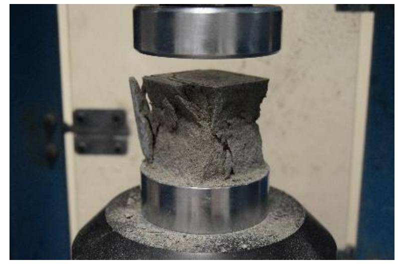

AKDOT-Z-0420-6

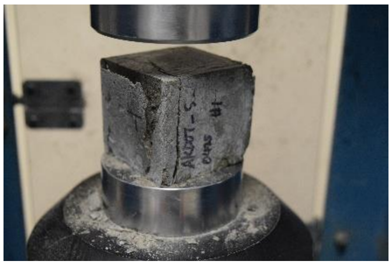
E.1.2 Round 1 Batch 0425218

E.1.2.1 7-Day Test (05/02/2018)

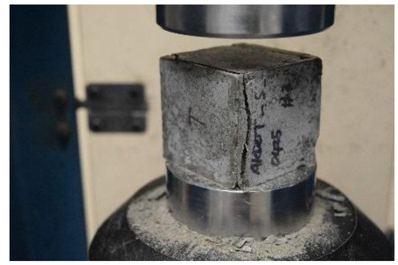

UAF-A-0425-1


UAF-A-0425-2


UAF-A-0425-3


AKDOT-S-0425-1


AKDOT-S-0425-2


AKDOT-S-0425-3


AKDOT-T-0425-1


AKDOT-T-0425-2


AKDOT-T-0425-3

E.1.2.2 28-Day Test (05/23/2018)


AKDOT-S-0425-4


AKDOT-S-0425-5


AKDOT-S-0425-6

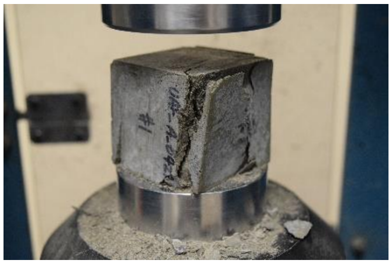

AKDOT-T-0425-4

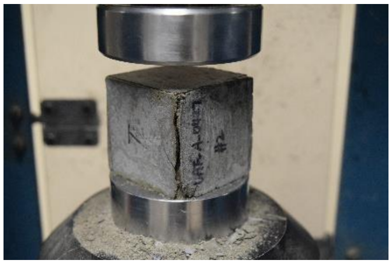

AKDOT-T-0425-5


AKDOT-T-0425-6

E.1.3 Round 1 Batch 0427218

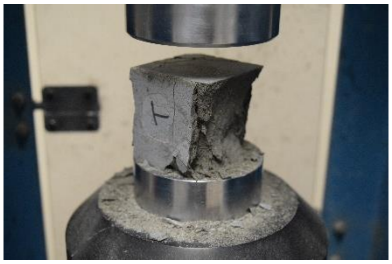
E.1.3.1 7-Day Test (05/04/2018)

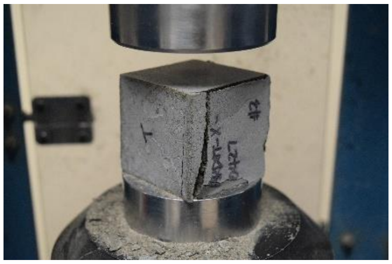

UAF-A-0427-1

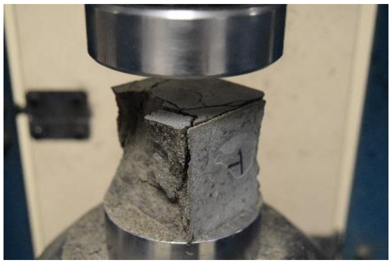

UAF-A-0427-2

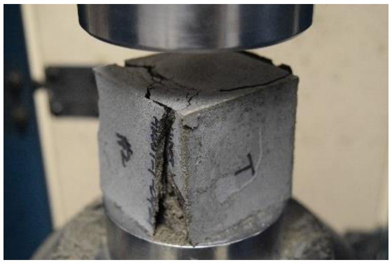

UAF-A-0427-3

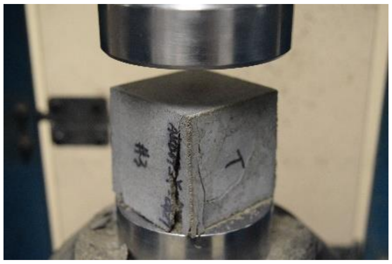

AKDOT-X-0427-1

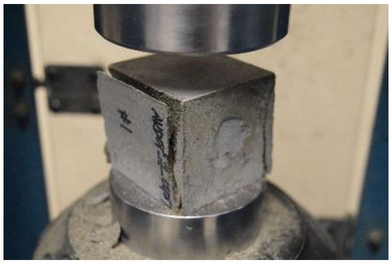

AKDOT-X-0427-2

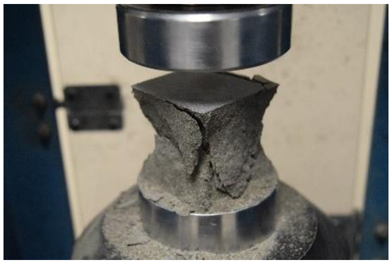

AKDOT-X-0427-3

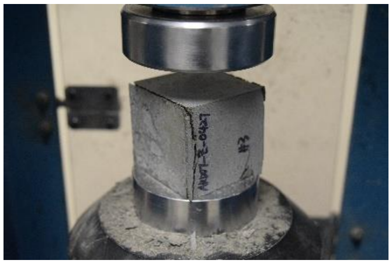

AKDOT-Y-0427-1


AKDOT-Y-0427-2


AKDOT-Y-0427-3


AKDOT-Z-0427-1


AKDOT-Z-0427-2


AKDOT-Z-0427-3

E.1.3.2 28-Day Test (05/25/2018)

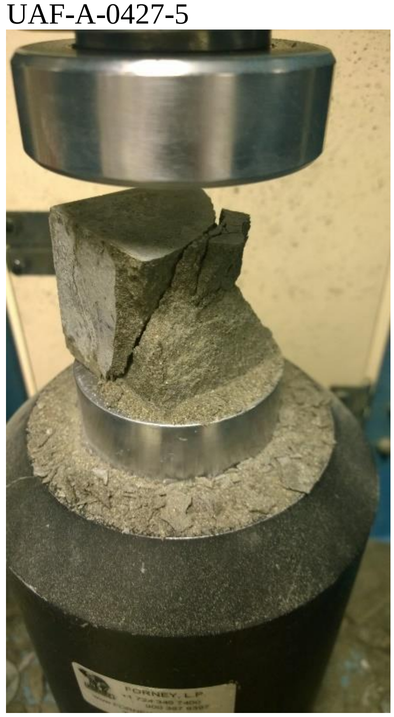
Cubes by Technicians A, X, Y, and Z respectively by row

UAF-A-0427-4

UAF-A-0427-5

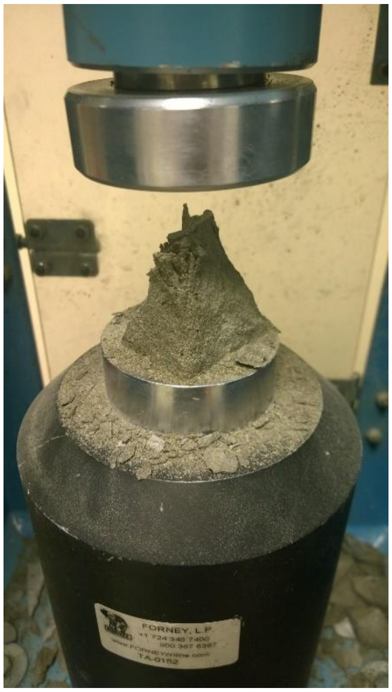
UAF-A-0427-6

AKDOT-X-0427-4

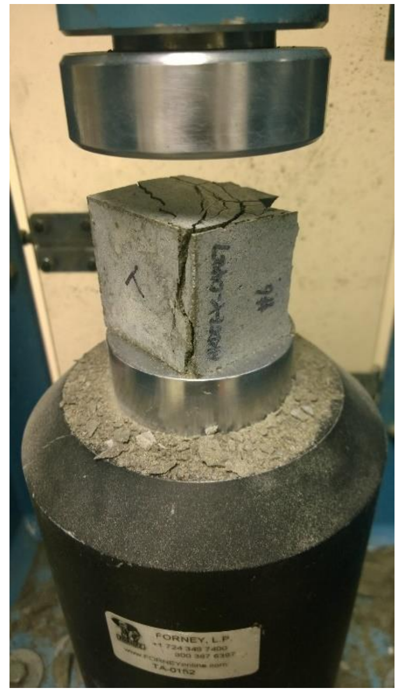


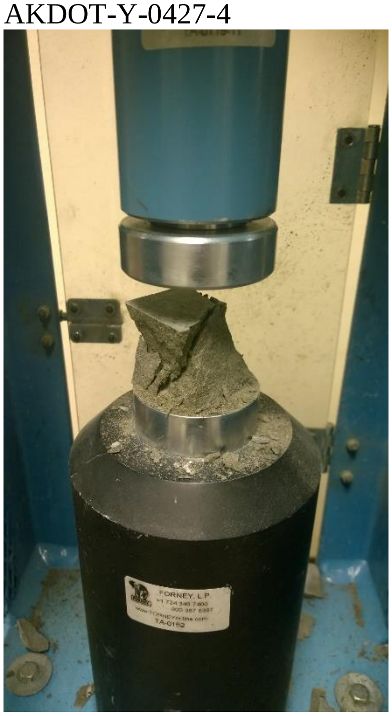
AKDOT-X-0427-5

AKDOT-X-0427-6

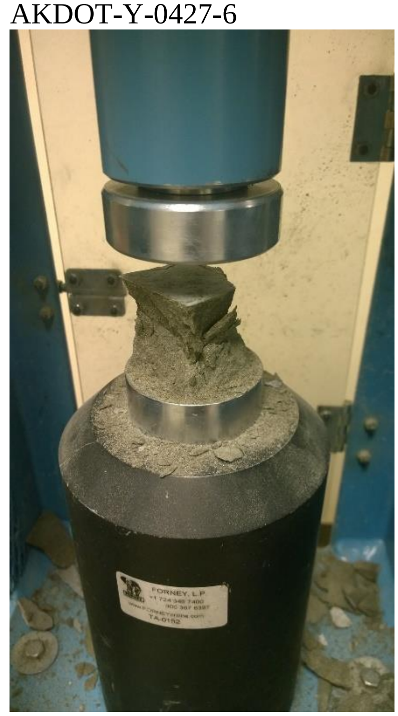

AKDOT-Y-0427-4


AKDOT-Y-0427-5


AKDOT-Y-0427-6

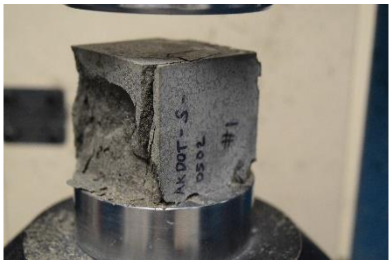

AKDOT-Z-0427-4


AKDOT-Z-0427-5

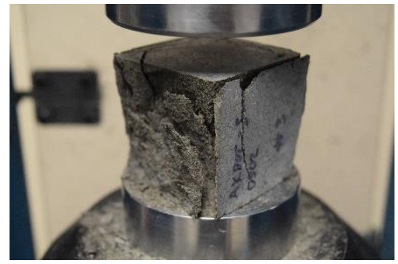

AKDOT-Z-0427-6

E.1.4 Round 1 Batch 050218

E.1.4.1 7-Day Test (05/09/2018)


AKDOT-S-0502-1


AKDOT-S-0502-2


AKDOT-S-0502-3


AKDOT-T-0502-1


AKDOT-T-0502-2


AKDOT-T-0502-3

E.1.4.2 28-Day Test (05/30/2018)


AKDOT-S-0502-4


AKDOT-S-0502-5


AKDOT-S-0502-6


AKDOT-T-0502-4


AKDOT-T-0502-5


AKDOT-T-0502-6

E.1.5 Round 1 Batch 050418

E.1.5.1 7-Day Test (05/11/2018)

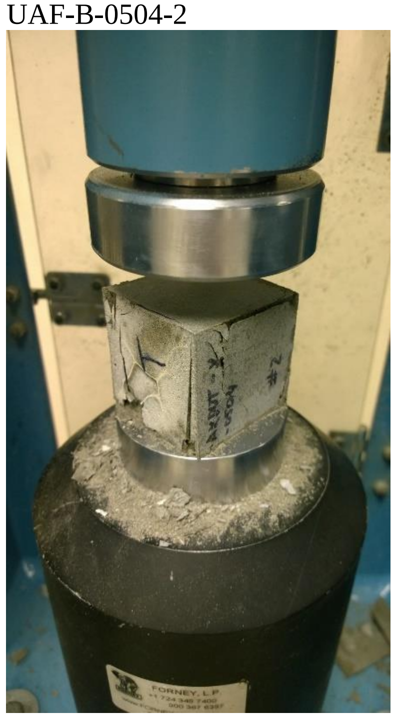
Cubes by Technicians B, X, Y, and Z respectively by row

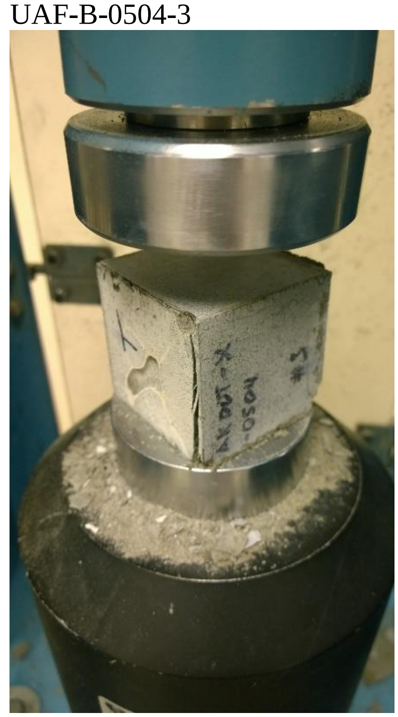

UAF-B-0504-1


UAF-B-0504-2

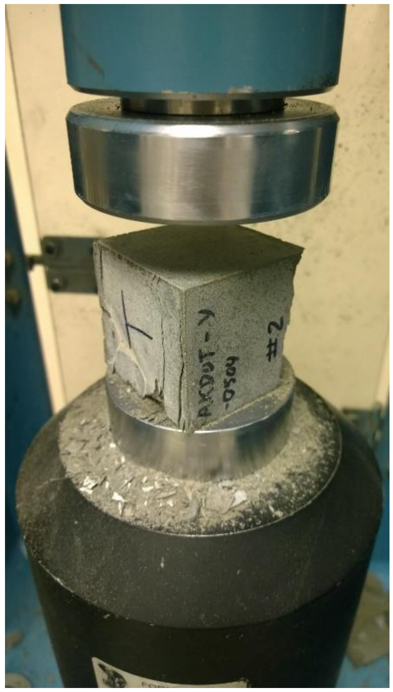

UAF-B-0504-3


AKDOT-X-0504-1


AKDOT-X-0504-2


AKDOT-X-0504-3

AKDOT-Y-0504-1



AKDOT-Y-0504-2

AKDOT-Y-0504-3

AKDOT-Z-0504-1

AKDOT-Z-0504-2

AKDOT-Z-0504-3

E.1.5.2 28-Day Test (06/01/2018)


UAF-B-0504-4


UAF-B-0504-5


UAF-B-0504-6


AKDOT-X-0504-4


AKDOT-X-0504-5


AKDOT-X-0504-6

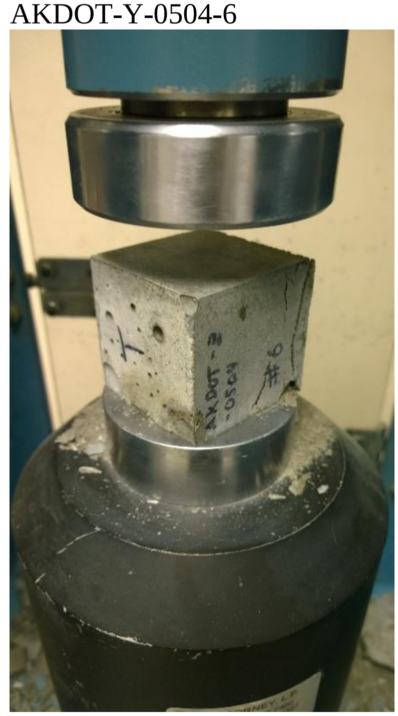

AKDOT-Y-0504-4


AKDOT-Y-0504-5


AKDOT-Y-0504-6

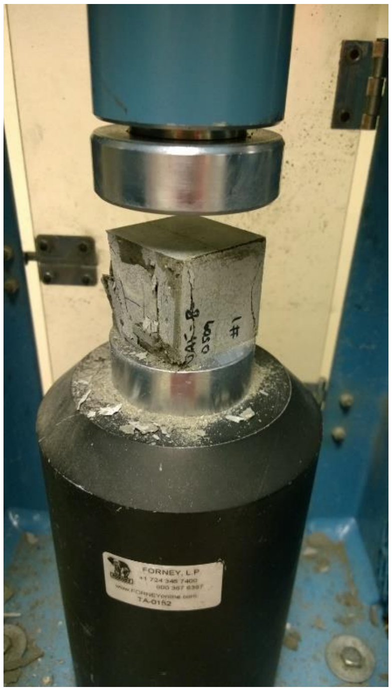

AKDOT-Z-0504-4


AKDOT-Z-0504-5


AKDOT-Z-0504-6

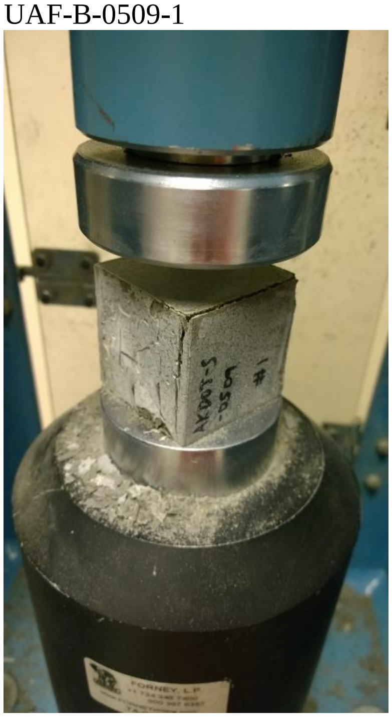
E.1.6 Round 1 Batch 050918

E.1.6.1 7-Day Test (05/16/2018)


UAF-B-0509-1


UAF-B-0509-2


UAF-B-0509-3


AKDOT-S-0509-1


AKDOT-S-0509-2


AKDOT-S-0509-3

E.1.6.2 28-Day Test (06/06/2018)

UAF-B-0509-4

UAF-B-0509-5

UAF-B-0509-6

AKDOT-S-0509-4

AKDOT-S-0509-5

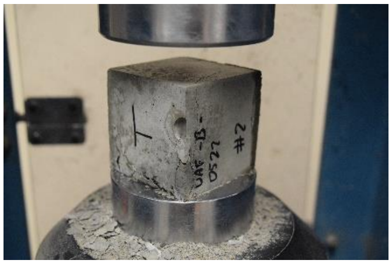
AKDOT-S-0509-6

E.2 Round 2

E.2.1 Round 2 Batch 052218

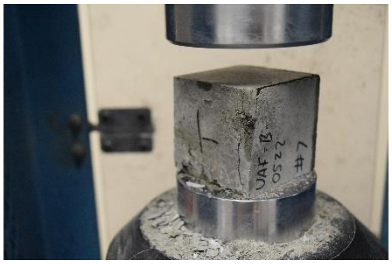
E.2.1.1 1-Day Test (05/23/18)

UAF-B-0522-1

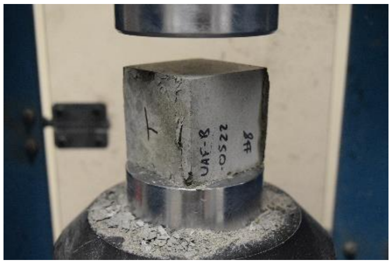


UAF-B-0522-2

UAF-B-0522-3



UAF-B-0522-7



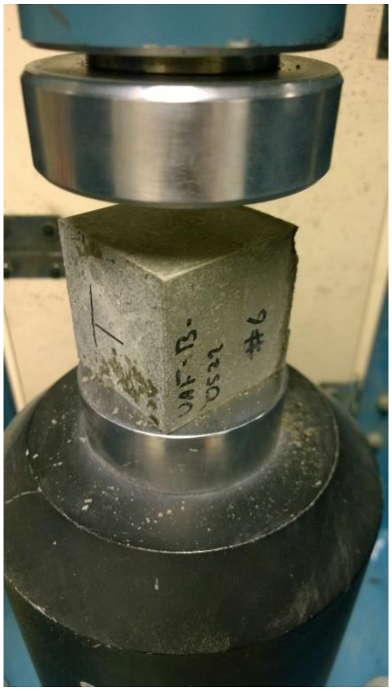
UAF-B-0522-8

UAF-B-0522-9

E.2.1.2 3-Day Test (05/25/2018)

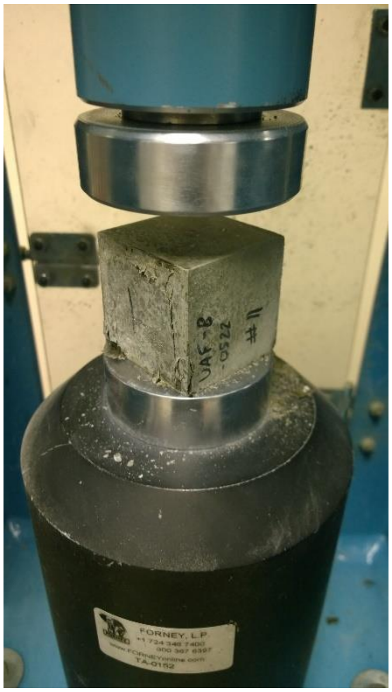
UAF-B-0522-4

UAF-B-0522-5



UAF-B-0522-6

UAF-B-0522-10



UAF-B-0522-11

UAF-B-0522-12

E.2.1.3 7-Day Test (05/29/2018)


UAF-B-0522-13


UAF-B-0522-14


UAF-B-0522-15


UAF-B-0522-19


UAF-B-0522-20


UAF-B-0522-21

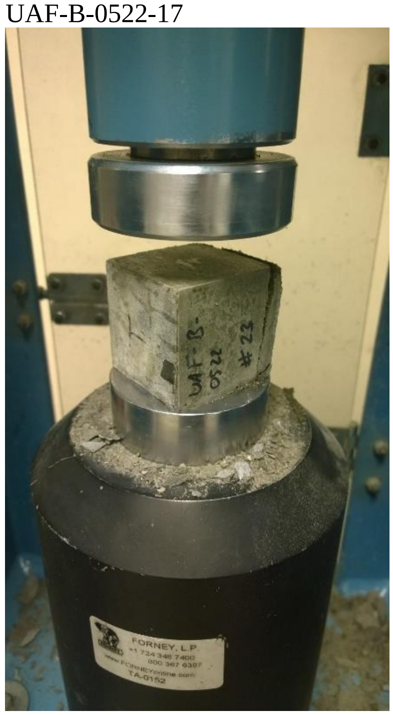
E.2.1.4 28-Day Test (06/19/2018)


UAF-B-0522-16

UAF-B-0522-17

UAF-B-0522-18

UAF-B-0522-22

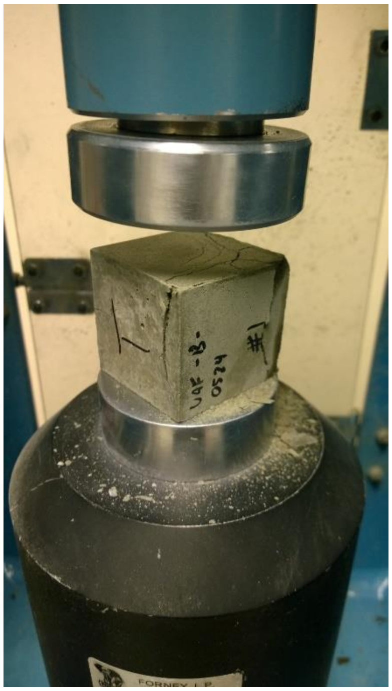


UAF-B-0522-23

UAF-B-0522-24

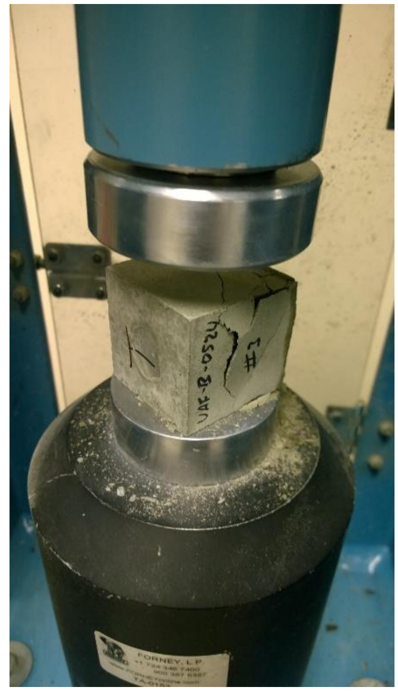
E.2.2 Round 2 Batch 052418

E.2.2.1 1-Day Test (05/25/18)



UAF-B-0524-1

UAF-B-0524-2



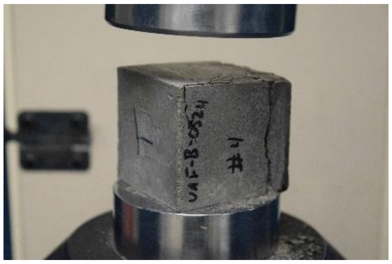
UAF-B-0524-3

UAF-B-0524-7

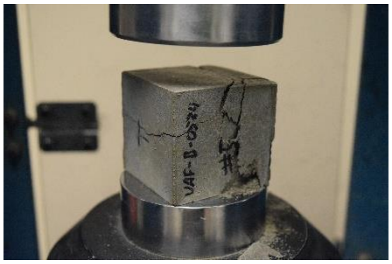
UAF-B-0524-8

UAF-B-0524-9

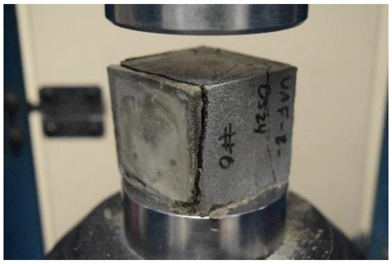
E.2.2.2 3-Day Test (05/27/2018)



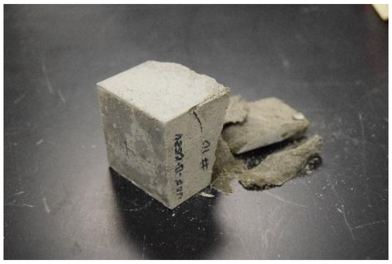
UAF-B-0524-4



UAF-B-0524-5



UAF-B-0524-6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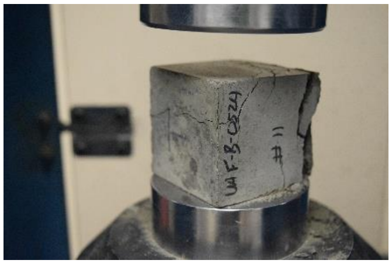
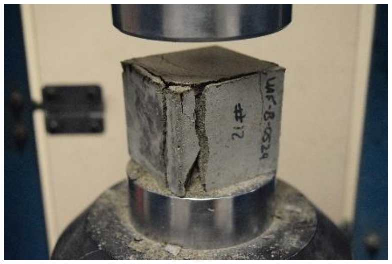
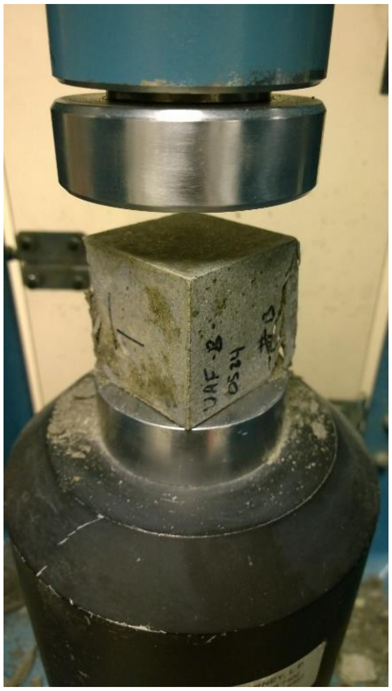


UAF-B-0524-11



UAF-B-0524-12

E.2.2.3 7-Day Test (05/31/2018)


UAF-B-0524-13


UAF-B-0524-14


UAF-B-0524-15


UAF-B-0524-19


UAF-B-0524-20

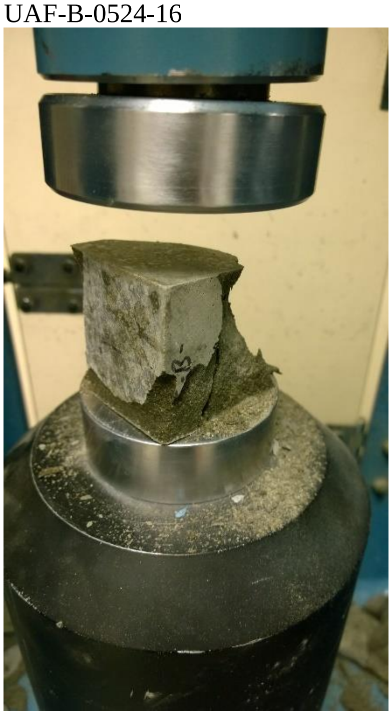

UAF-B-0524-21

E.2.2.4 28-Day Test (06/21/2018)


UAF-B-0524-16


UAF-B-0524-17


UAF-B-0524-18


UAF-B-0524-22


UAF-B-0524-23


UAF-B-0524-24

E.2.3 Round 2 Batch 060118

E.2.3.1 1-Day Test (06/02/2018)

UAF-A-0601-1

UAF-A-0601-2

UAF-A-0601-3

UAF-A-0601-7

UAF-A-0601-8

UAF-A-0601-9

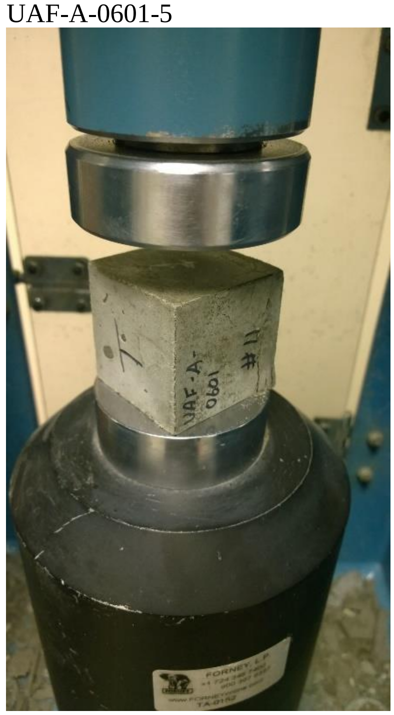
E.2.3.2 3-Day Test (06/04/2018)

UAF-A-0601-4

UAF-A-0601-5

UAF-A-0601-6

UAF-A-0601-10

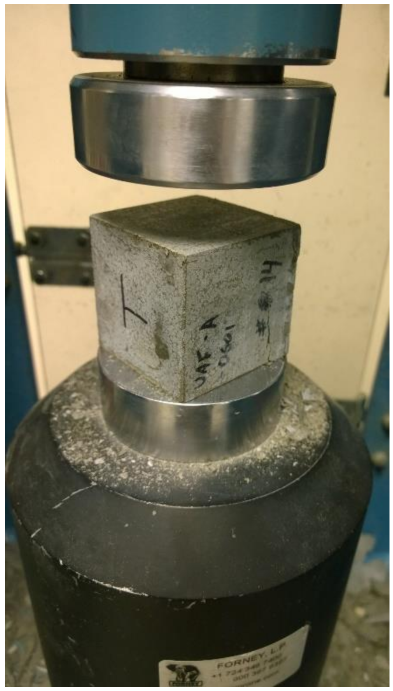


UAF-A-0601-11

UAF-A-0601-12

E.2.3.3 7-Day Test (06/08/2018)


UAF-A-0601-13


UAF-A-0601-14

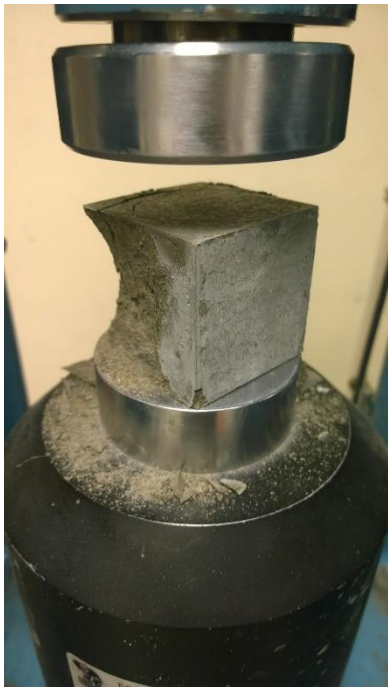

UAF-A-0601-15


UAF-A-0601-19

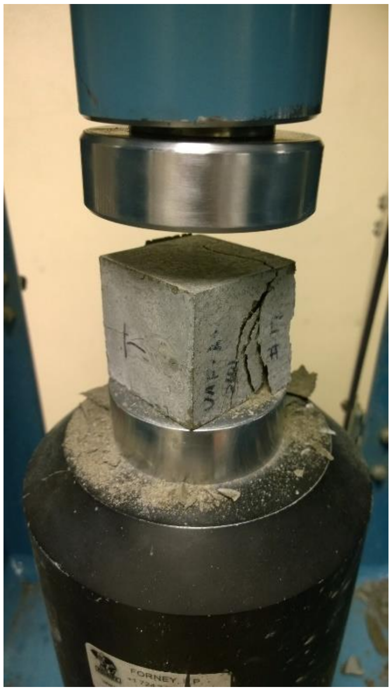

UAF-A-0601-20


UAF-A-0601-21

E.2.3.4 28-Day Test (06/29/2018)



UAF-A-0601-16



UAF-A-0601-17

UAF-A-0601-18

UAF-A-0601-22

UAF-A-0601-23

UAF-A-0601-24

E.2.4 Round 2 Batch 060518

E.2.4.1 1-Day Test (06/06/2018)

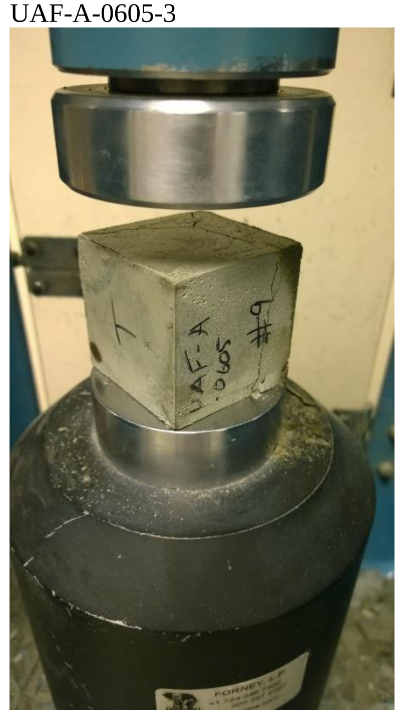
UAF-A-0605-1

UAF-A-0605-2

UAF-A-0605-3

UAF-A-0605-7

UAF-A-0605-8



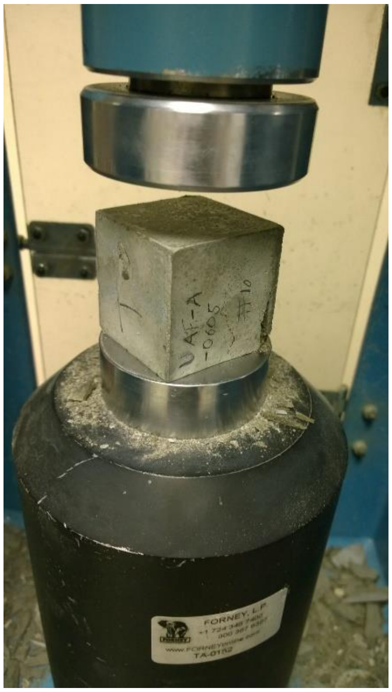
UAF-A-0605-9

E.2.4.2 3-Day Test (06/08/2018)

UAF-A-0605-4

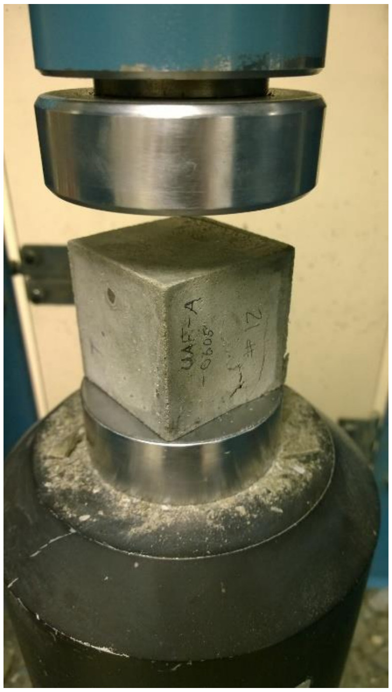
UAF-A-0605-5

UAF-A-0605-6



UAF-A-0605-10

UAF-A-0605-11

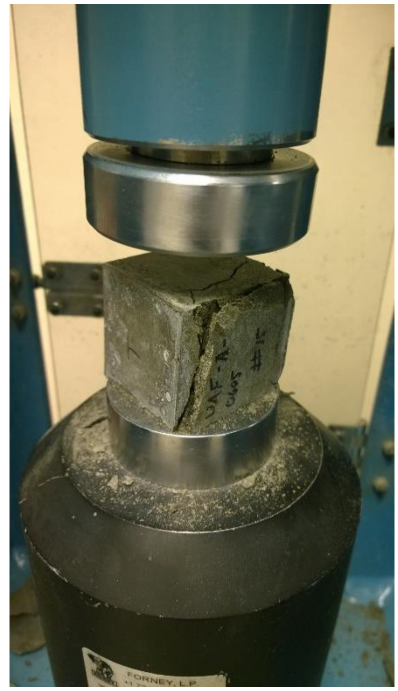


UAF-A-0605-12

E.2.4.3 7-Day Test (06/12/2018)

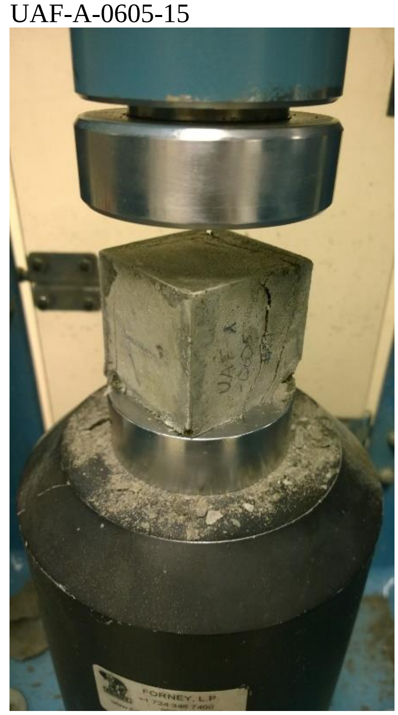
UAF-A-0605-13


UAF-A-0605-14


UAF-A-0605-15


UAF-A-0605-19


UAF-A-0605-20


UAF-A-0605-21

E.2.4.4 28-Day Test (07/03/2018)

UAF-A-0605-16

UAF-A-0605-17

UAF-A-0605-18

UAF-A-0605-22

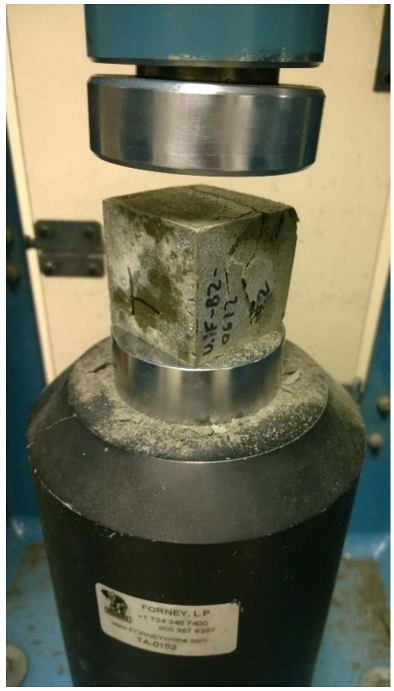
UAF-A-0605-23

UAF-A-0605-24

E.2.5 Round 2 Batch 061218

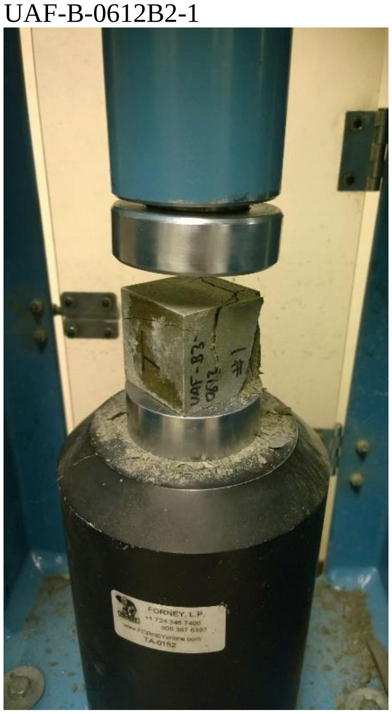
E.2.5.1 3-Day Test (06/15/2018)

UAF-B-0612B2-1

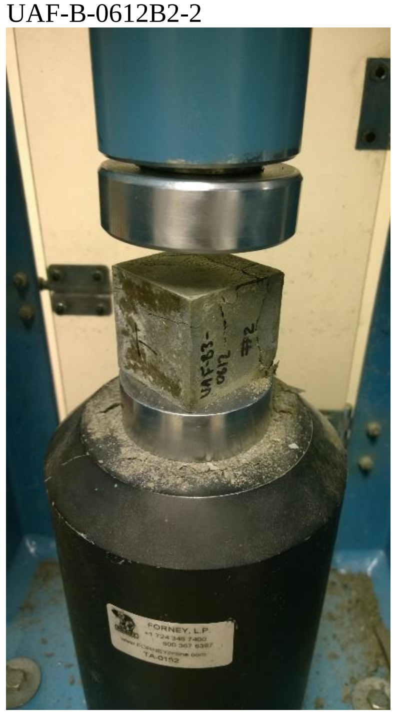


UAF-B-0612B2-2


UAF-B-0612B2-3



UAF-B-0612B3-1



UAF-B-0612B3-2

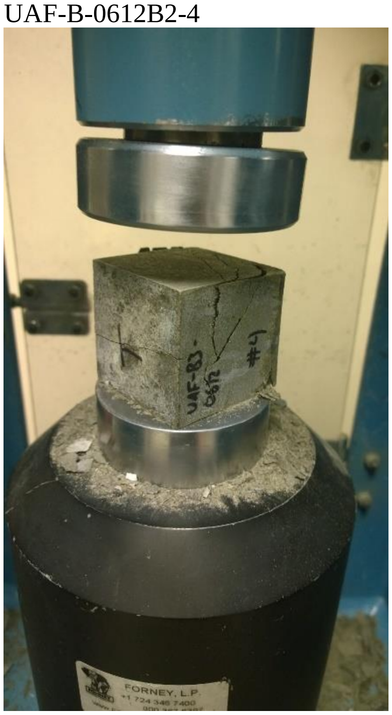
UAF-B-0612B3-3

E.2.5.2 7-Day Test (06/19/2018)

UAF-B-0612B2-4

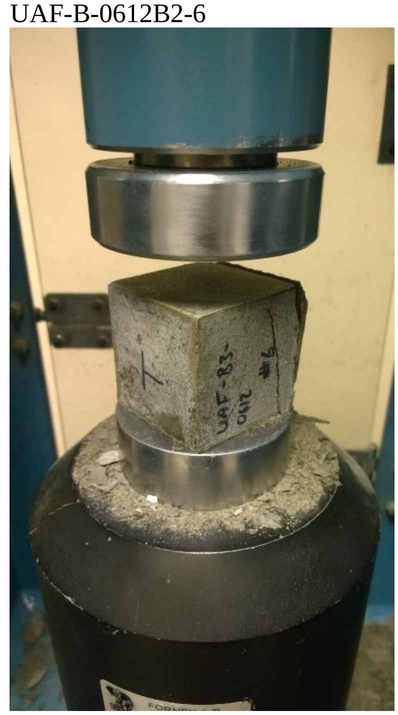
UAF-B-0612B2-5

UAF-B-0612B2-6



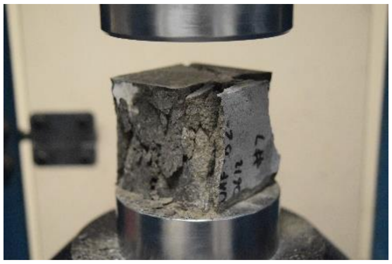
UAF-B-0612B3-4

UAF-B-0612B3-5



UAF-B-0612B3-6

E.2.5.3 28-Day Test (07/10/2018)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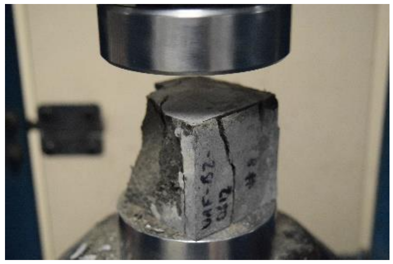
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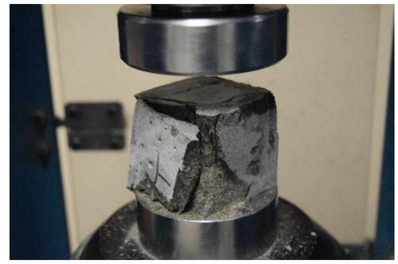
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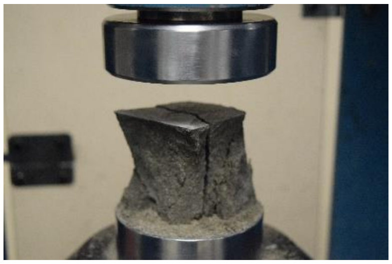
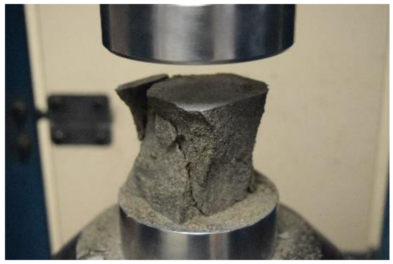

UAF-B-0612B3-7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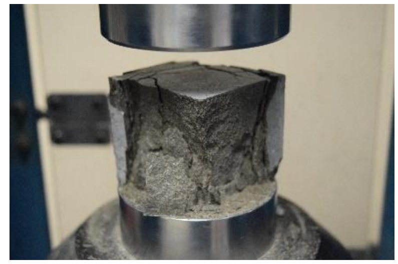
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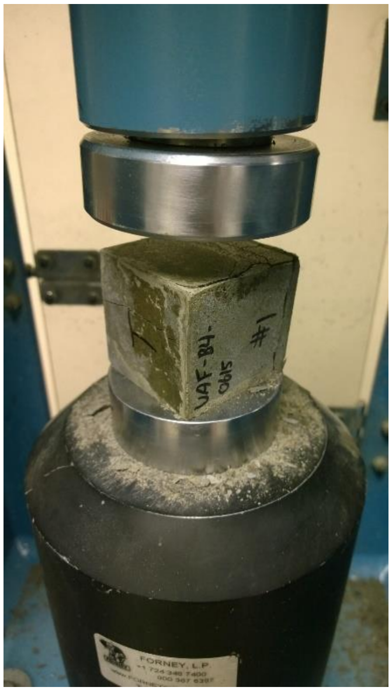
E.2.6 Round 2 Batch 061518

E.2.6.1 3-Day Test (06/18/2018)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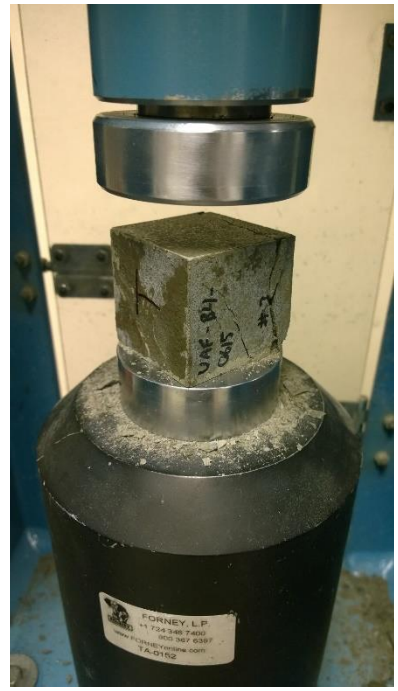
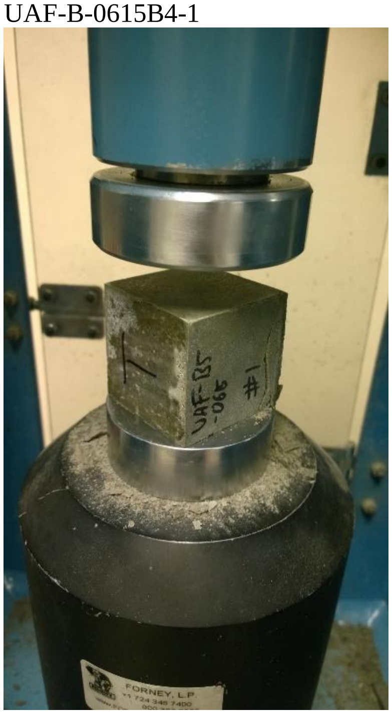
UAF-B-0615B4-2


UAF-B-0615B4-3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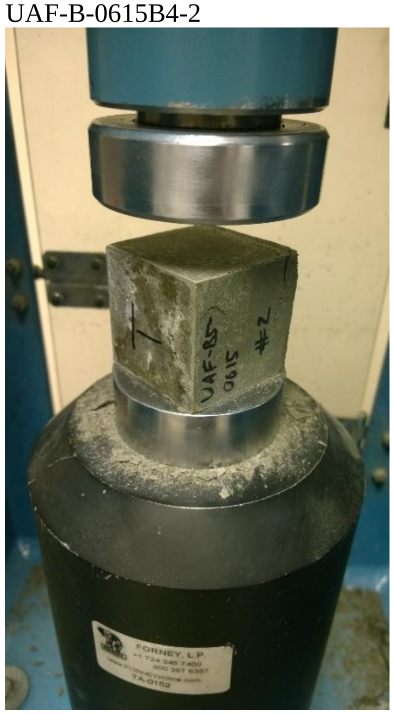
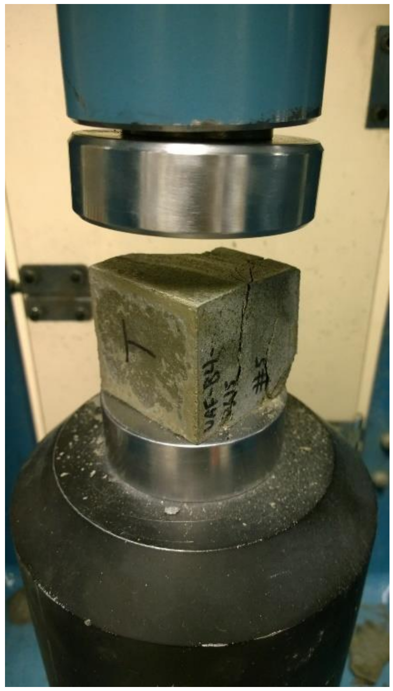

UAF-B-0615B5-2


UAF-B-0615B5-3

E.2.6.2 7-Day Test (06/22/2018)


UAF-B-0615B4-4


UAF-B-0615B4-5

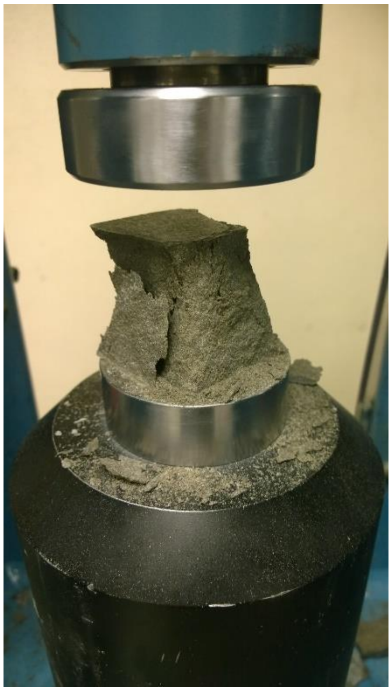

UAF-B-0615B4-6

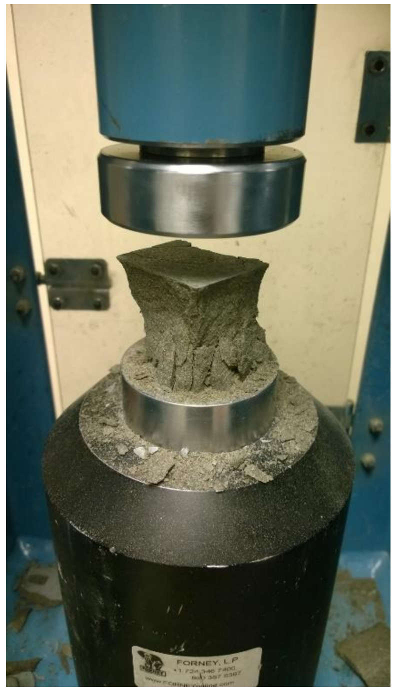

UAF-B-0615B5-4


UAF-B-0615B5-5


UAF-B-0615B5-6

E.2.6.3 28-Day Test (07/13/2018)

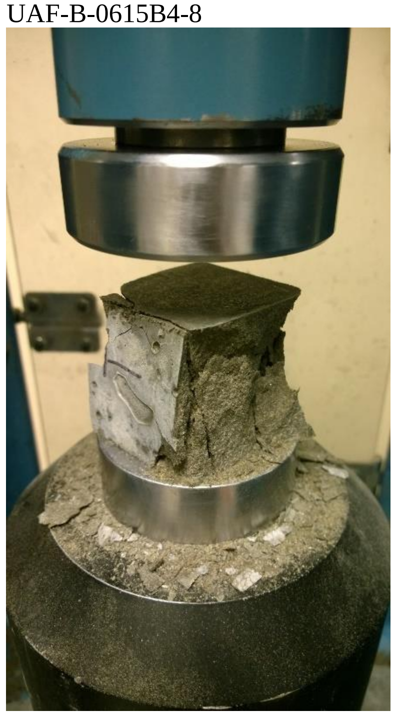

UAF-B-0615B4-7



UAF-B-0615B4-8

UAF-B-0615B4-9


UAF-B-0615B5-7

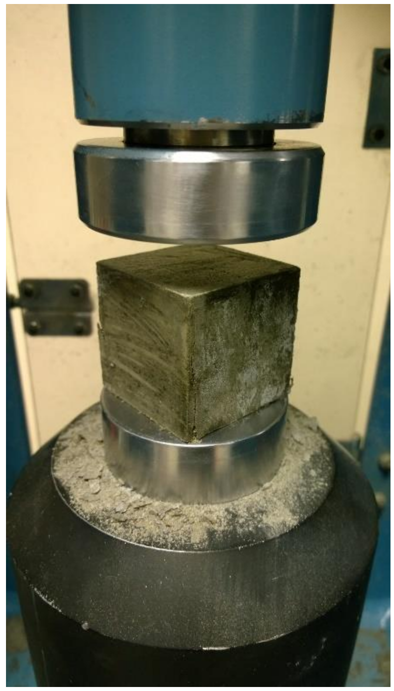

UAF-B-0615B5-8


UAF-B-0615B5-9

E.2.7 Round 2 Batch 062218

E.2.7.1 3-Day Test (06/25/2018)

UAF-B-0622B5-1



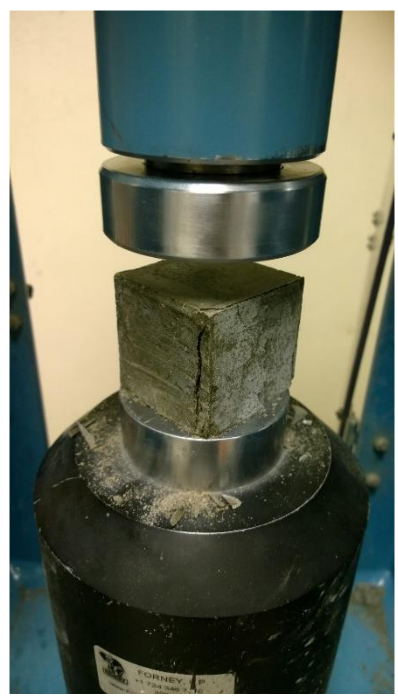
UAF-B-0622B5-2

UAF-B-0622B5-3

E.2.7.2 7-Day Test (06/29/2018)

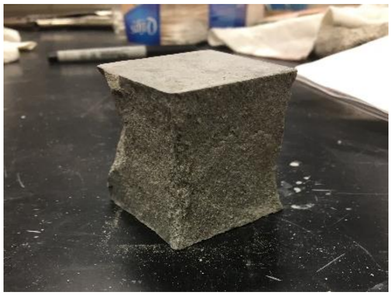
UAF-B-0622B5-4

UAF-B-0622B5-5



UAF-B-0622B5-6

E.2.7.3 28-Day Test (07/20/2018)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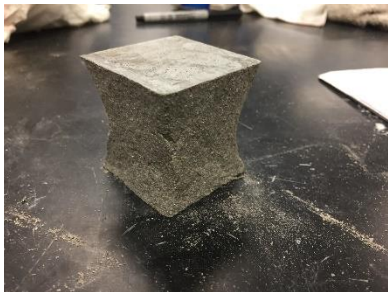
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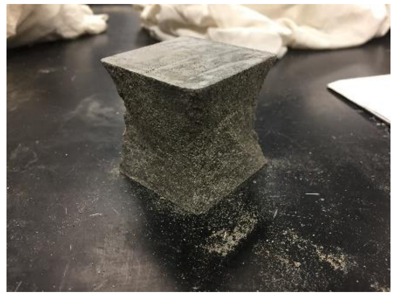
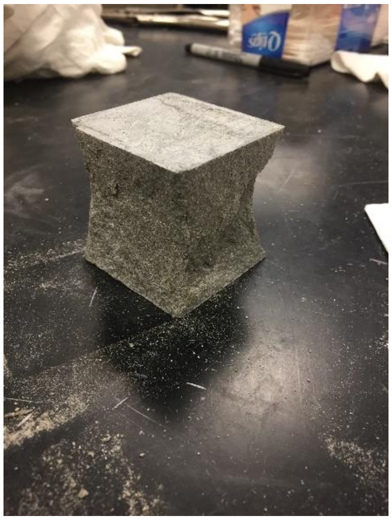

UAF-B-0622B3-3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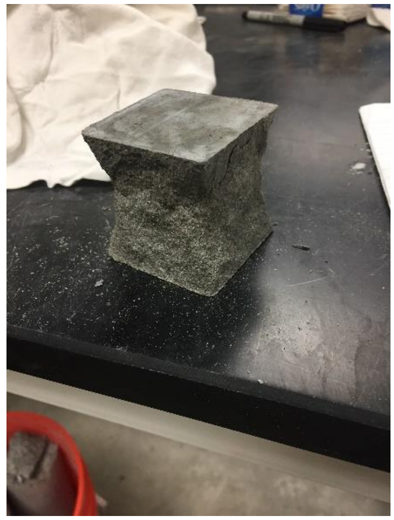
UAF-B-0622B4-2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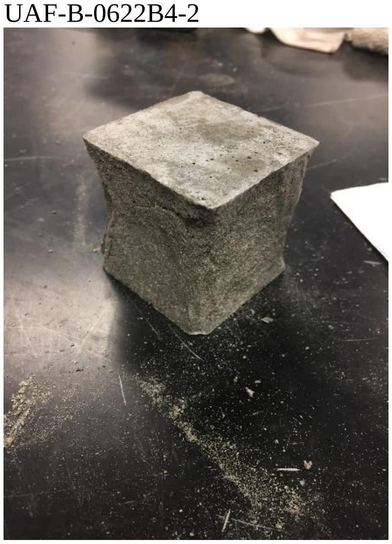
UAF-B-0622B5-7

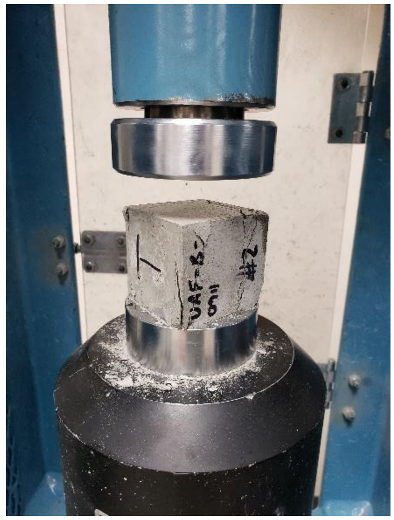

UAF-B-0622B5-8


UAF-B-0622B5-9

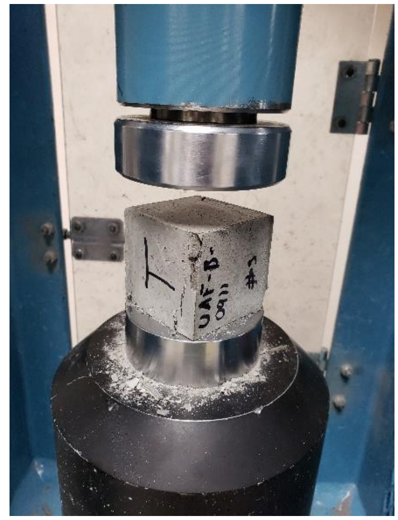
E.2.8 Round 2 Batch 091118

E.2.8.1 1-Day Test (09/12/2018)

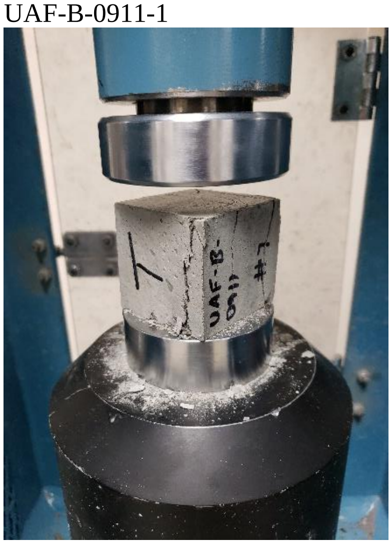
UAF-B-0911-1



UAF-B-0911-2

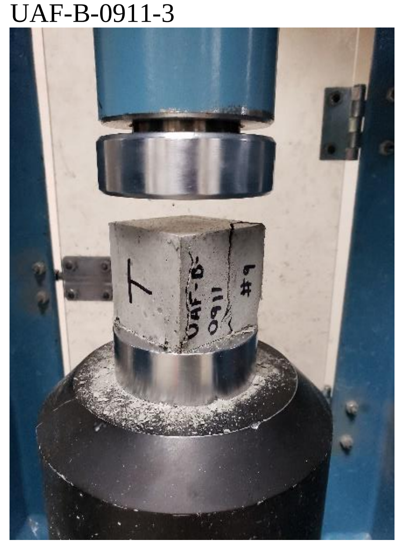


UAF-B-0911-3



UAF-B-0911-7

UAF-B-0911-8



UAF-B-0911-9

E.2.8.2 3-Day Test (09/14/2018)

UAF-B-0911-4

UAF-B-0911-5

UAF-B-0911-6

UAF-B-0911-10

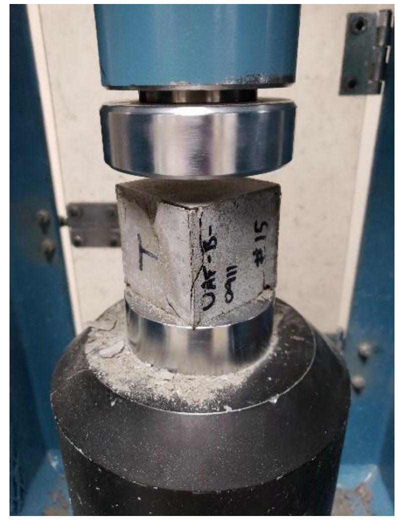
UAF-B-0911-11

UAF-B-0911-12

E.2.8.3 7-Day Test (09/18/2018)

UAF-B-0911-13

UAF-B-0911-14



UAF-B-0911-15

UAF-B-0911-19

UAF-B-0911-20

UAF-B-0911-21

E.2.8.4 28-Day Test (10/09/2018)


UAF-B-0911-16


UAF-B-0911-17


UAF-B-0911-18


UAF-B-0911-22


UAF-B-0911-23


UAF-B-0911-24

E.2.9 Round 2 Batch 111318

E.2.9.1 1-Day Test (11/14/2018)

UAF-B-1113-1

UAF-B-1113-2

UAF-B-1113-3

UAF-B-1113-7

UAF-B-1113-8

UAF-B-1113-9

E.2.9.2 3-Day Test (11/16/2018)

UAF-B-1113-4

UAF-B-1113-5

UAF-B-1113-6

UAF-B-1113-10

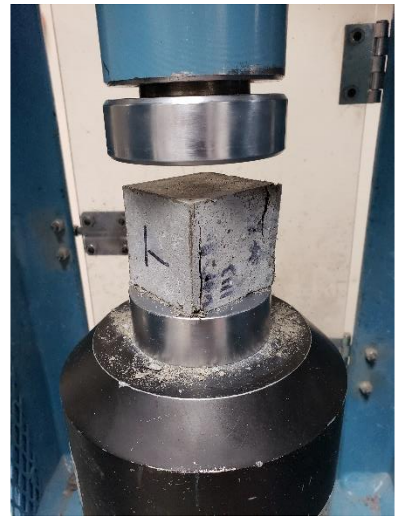
UAF-B-1113-11

UAF-B-1113-12

E.2.9.3 7-Day Test (11/20/2018)


UAF-B-1113-13


UAF-B-1113-14


UAF-B-1113-15


UAF-B-1113-19


UAF-B-1113-20


UAF-B-1113-21

E.2.9.4 28-Day Test (12/11/2018)


UAF-B-1113-16


UAF-B-1113-17


UAF-B-1113-18


UAF-B-1113-22


UAF-B-1113-23

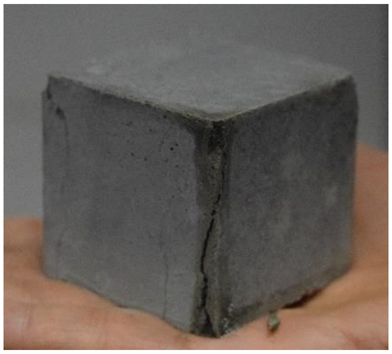

UAF-B-1113-24

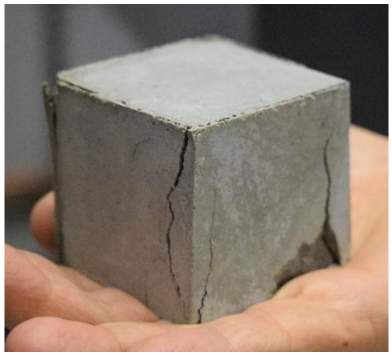
E.3 Round 3

E.3.1 Round 3 Batch 081418

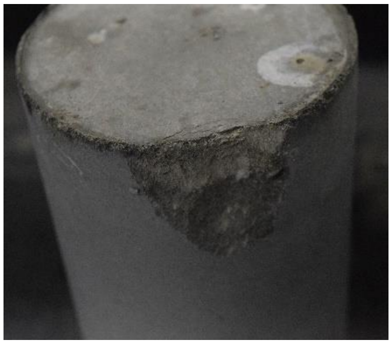
E.3.1.1 1-Day Test at DOT&PF-NR (08/15/18)


UAF-0814-D-1


UAF-0814-D-2


UAF-0814-D-3


UAF-0814-D-C1


UAF-0814-D-C2


UAF-0814-D-C3

E.3.1.2 1-Day Test at UAF (08/15/18)

UAF-0814-U-1

UAF-0814-U-2


UAF-0814-U-3


UAF-0814-U-C1


UAF-0814-U-C2


UAF-0814-U-C3

E.3.1.3 3-Day Test at UAF (08/17/18)

UAF-0814-U-4

UAF-0814-U-5

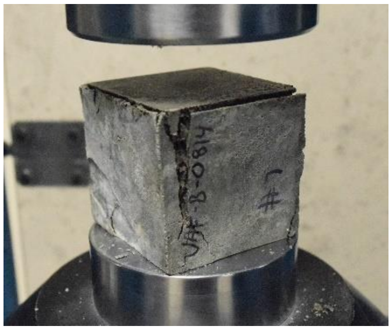
UAF-0814-U-6


UAF-0814-U-C4

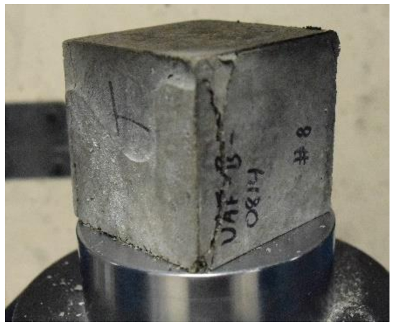

UAF-0814-U-C5


UAF-0814-U-C6

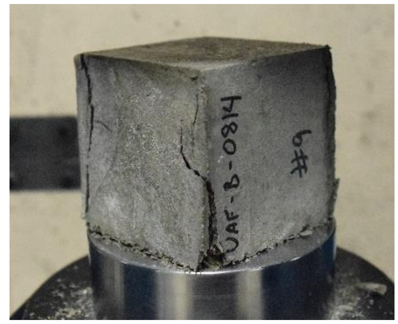
E.3.1.4 7-Day Test at UAF (08/21/18)



UAF-0814-U-7



UAF-0814-U-8



UAF-0814-U-9

UAF-0814-U-C7

UAF-0814-U-C8

UAF-0814-U-C9

E.3.1.5 28-Day Test at UAF (09/11/18)


UAF-0814-U-10


UAF-0814-U-11


UAF-0814-U-12


UAF-0814-U-C10


UAF-0814-U-C11


UAF-0814-U-C12

E.3.2 Round 3 Batch 082118

E.3.2.1 1-Day Test at DOT&PF-NR (08/22/18)



UAF-0821-D-1 ~ D-3



UAF-0821-D-C1 ~ C3

E.3.2.2 1-Day Test at UAF (08/22/18)


UAF-0821-U-1


UAF-0821-U-2

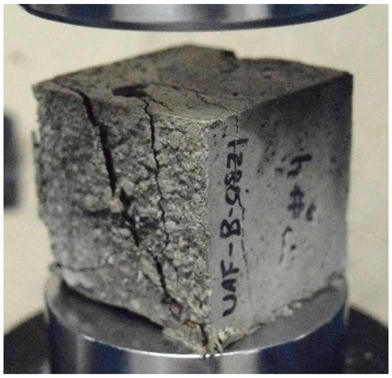

UAF-0821-U-3


UAF-0821-U-C1

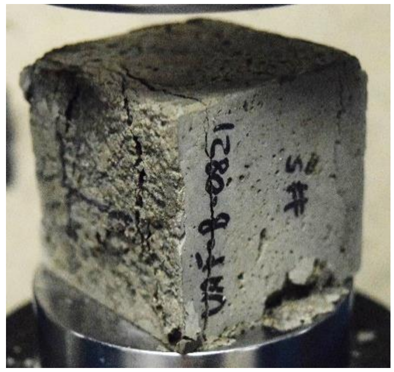

UAF-0821-U-C2


UAF-0821-U-C3

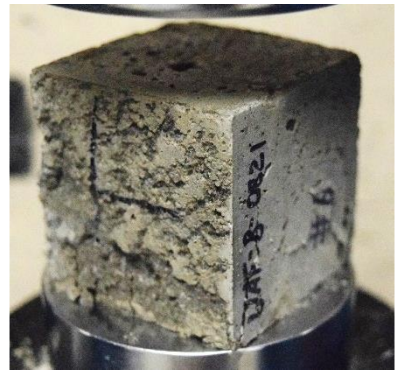
E.3.2.3 3-Day Test at UAF (08/24/18)



UAF-0821-U-4

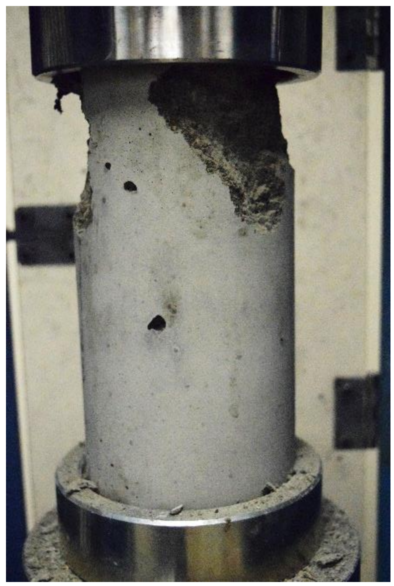


UAF-0821-U-5

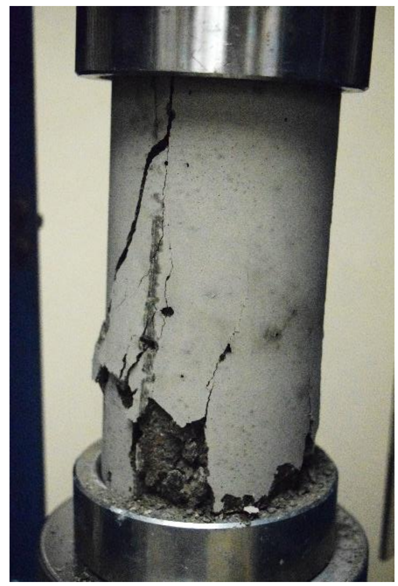


UAF-0821-U-6

UAF-0821-U-C4



UAF-0821-U-C5



UAF-0821-U-C6

E.3.2.4 7-Day Test at UAF (08/28/18)


UAF-0821-U-7


UAF-0821-U-8


UAF-0821-U-9


UAF-0821-U-C7


UAF-0821-U-C8


UAF-0821-U-C9

E.3.2.5 28-Day Test at UAF (09/18/18)


UAF-0821-U-10


UAF-0821-U-11


UAF-0821-U-12


UAF-0821-U-C10


UAF-0821-U-C11


UAF-0821-U-C12

E.3.3 Round 3 Batch 082818

E.3.3.1 1-Day Test at DOT&PF-NR (08/29/18)


UAF-0828-D-C1


UAF-0828-D-C2


UAF-0828-D-C3

E.3.3.2 1-Day Test at UAF (08/29/18)


UAF-0828-U-1


UAF-0828-U-2


UAF-0828-U-3


UAF-0828-U-C1


UAF-0828-U-C2


UAF-0828-U-C3

E.3.3.3 3-Day Test at UAF (08/31/18)

UAF-0828-U-4

UAF-0828-U-5

UAF-0828-U-6

UAF-0828-U-C4

UAF-0828-U-C5

UAF-0828-U-C6

E.3.3.4 7-Day Test at UAF (09/04/18)


UAF-0828-U-7


UAF-0828-U-8


UAF-0828-U-9


UAF-0828-U-C7


UAF-0828-U-C8


UAF-0828-U-C9

E.3.3.5 28-Day Test at UAF (09/25/18)

UAF-0828-U-10

UAF-0828-U-11

UAF-0828-U-12

UAF-0828-U-C10

UAF-0828-U-C11

UAF-0828-U-C12

E.3.4 Round 3 Batch 090418

E.3.4.1 1-Day Test at DOT&PF-NR (09/05/18)

UAF-0904-D-1

UAF-0904-D-2

UAF-0904-D-3

UAF-0904-D-C1

UAF-0904-D-C2

UAF-0904-D-C3

E.3.4.2 1-Day Test at UAF (09/05/18)

UAF-0904-U-1

UAF-0904-U-2

UAF-0904-U-3

UAF-0904-U-C1

UAF-0904-U-C2

UAF-0904-U-C3

E.3.4.3 3-Day Test at UAF (09/07/18)

UAF-0904-U-4

UAF-0904-U-5

UAF-0904-U-6

UAF-0904-U-C4

UAF-0904-U-C5

UAF-0904-U-C6

E.3.4.4 7-Day Test at UAF (09/11/18)


UAF-0904-U-7


UAF-0904-U-8


UAF-0904-U-9


UAF-0904-U-C7


UAF-0904-U-C8


UAF-0904-U-C9

E.3.4.5 28-Day Test at UAF (10/02/18)

UAF-0904-U-10

UAF-0904-U-11

UAF-0904-U-12

UAF-0904-U-C10

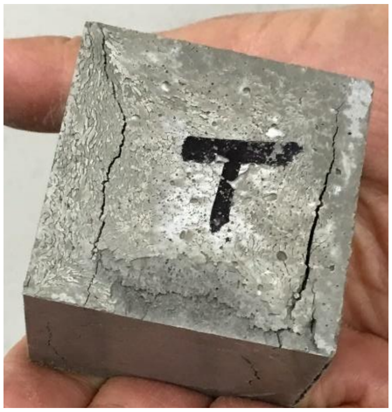
UAF-0904-U-C11

UAF-0904-U-C12

E.3.5 Round 3 Batch 092518

E.3.5.1 1-Day Test at DOT&PF-NR (09/26/18)


DOT-0925-D-1


DOT-0925-D-2


DOT-0925-D-3


DOT-0925-D-C1


DOT-0925-D-C2


DOT-0925-D-C3

E.3.5.2 1-Day Test at UAF (09/26/18)

DOT-0925-U-1

DOT-0925-U-2

DOT-0925-U-3


DOT-0925-U-C1


DOT-0925-U-C2


DOT-0925-U-C3

E.3.5.3 3-Day Test at UAF (09/28/18)

DOT-0925-U-4

DOT-0925-U-5

DOT-0925-U-6

DOT-0925-U-C4

DOT-0925-U-C5

DOT-0925-U-C6

E.3.5.4 7-Day Test at UAF (10/02/18)

DOT-0925-U-7

DOT-0925-U-8

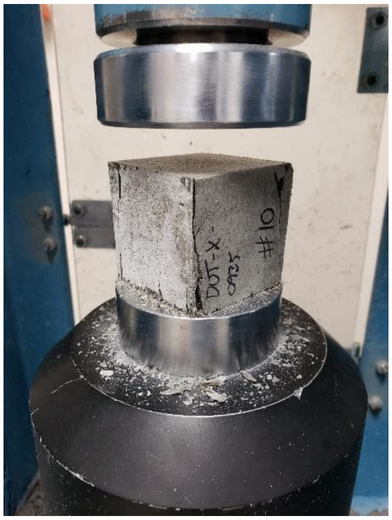
DOT-0925-U-9

DOT-0925-U-C7

DOT-0925-U-C8

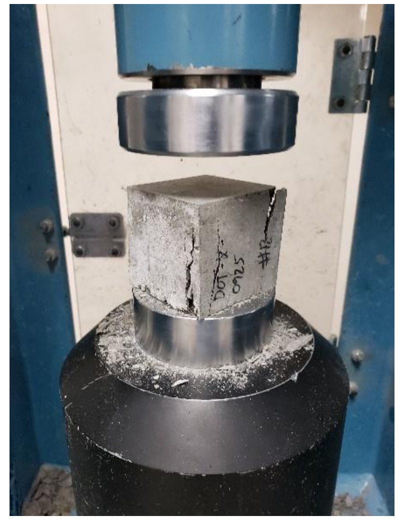
DOT-0925-U-C9

E.3.5.5 28-Day Test at UAF (10/23/18)



DOT-0925-U-10

DOT-0925-U-11



DOT-0925-U-12


DOT-0925-U-C10


DOT-0925-U-C11

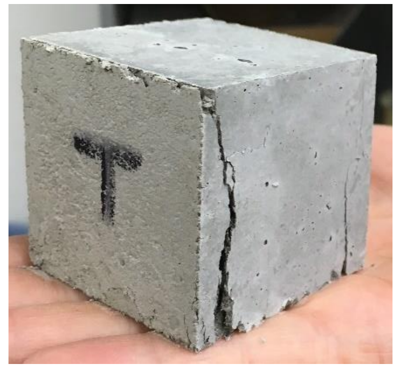

DOT-0925-U-C12

E.3.6 Round 3 Batch 100218

E.3.6.1 1-Day Test at DOT&PF-NR(10/03/18)

DOT-1002-D-1

DOT-1002-D-2



DOT-1002-D-3

DOT-1002-D-C2

DOT-1002-D-C3

E.3.6.2 1-Day Test at UAF (10/03/18)


DOT-1002-U-1


DOT-1002-U-2


DOT-1002-U-3


DOT-1002-U-C1


DOT-1002-U-C2


DOT-1002-U-C3

E.3.6.3 3-Day Test at UAF (10/05/18)


DOT-1002-U-4


DOT-1002-U-5


DOT-1002-U-6


DOT-1002-U-C4


DOT-1002-U-C5


DOT-1002-U-C6

E.3.6.4 7-Day Test at UAF (10/09/18)

DOT-1002-U-7

DOT-1002-U-8

DOT-1002-U-9

DOT-1002-U-C7

DOT-1002-U-C8

DOT-1002-U-C9

E.3.6.5 28-Day Test at UAF (10/30/18)


DOT-1002-U-10


DOT-1002-U-11


DOT-1002-U-12


DOT-1002-U-C10


DOT-1002-U-C11


DOT-1002-U-C12

E.3.7 Round 3 Batch 101618

E.3.7.1 1-Day Test at UAF (10/17/18)


UAF-1016-U-1


UAF-1016-U-2


UAF-1016-U-3


UAF-1016-U-C1


UAF-1016-U-C2


UAF-1016-U-C3

E.3.7.2 3-Day Test at UAF (10/19/18)


UAF-1016-U-4


UAF-1016-U-5


UAF-1016-U-6


UAF-1016-U-C4


UAF-1016-U-C5


UAF-1016-U-C6

E.3.7.3 7-Day Test at UAF (10/23/18)

UAF-1016-U-7

UAF-1016-U-8

UAF-1016-U-9

UAF-1016-U-C7

UAF-1016-U-C8

UAF-1016-U-C9

E.3.7.4 28-Day Test at UAF (11/13/18)


UAF-1016-U-10


UAF-1016-U-11


UAF-1016-U-12


UAF-1016-U-C10


UAF-1016-U-C11


UAF-1016-U-C12

E.4 Round 4

E.4.1 Round 4 Batch 112118

E.4.1.1 3-Day Test (11/24/18)

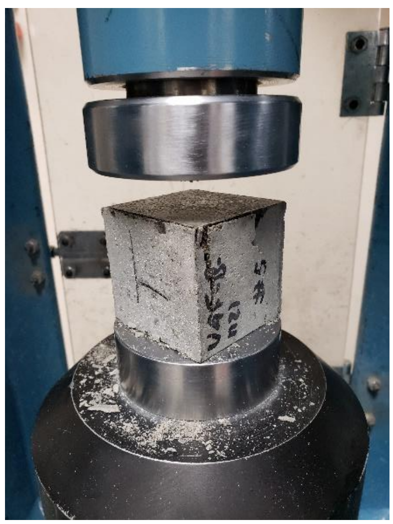

UAF-1121-1


UAF-1121-2


UAF-1121-3

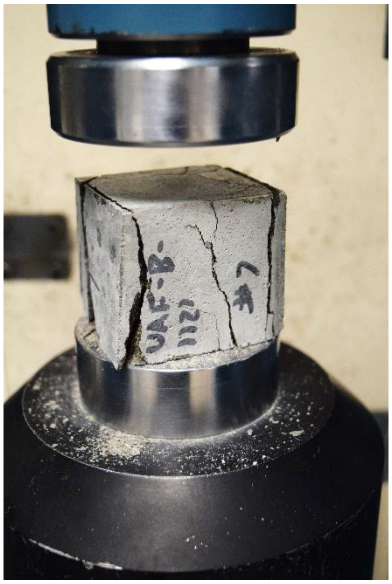
E.4.1.2 7-Day Test (11/28/18)


UAF-1121-4

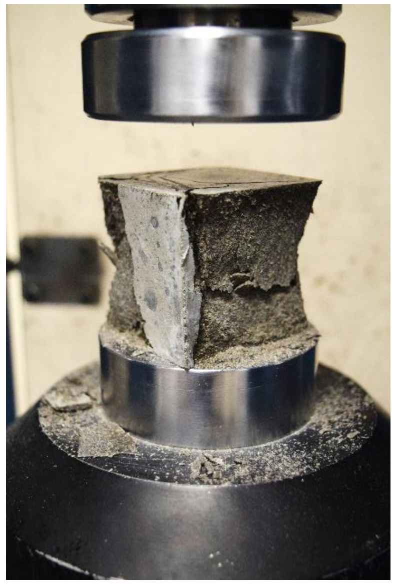

UAF-1121-5


UAF-1121-6

E.4.1.3 28-Day Test (12/19/18)



UAF-1121-7


UAF-1121-8

UAF-1121-9

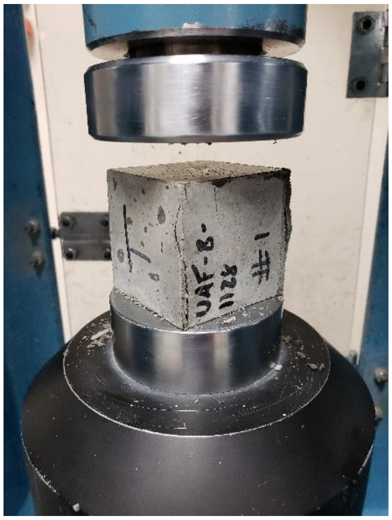
UAF-1121-R1


UAF-1121-R2


UAF-1121-R3

E.4.2 Round 4 Batch 112818

E.4.2.1 3-Day Test (12/01/18)


UAF-1128-1


UAF-1128-2


UAF-1128-3

E.4.2.2 7-Day Test (12/05/18)


UAF-1128-4


UAF-1128-5

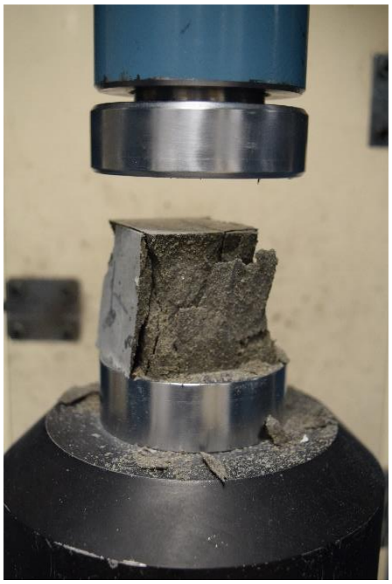

UAF-1128-6

E.4.2.3 28-Day Test (12/26/18)

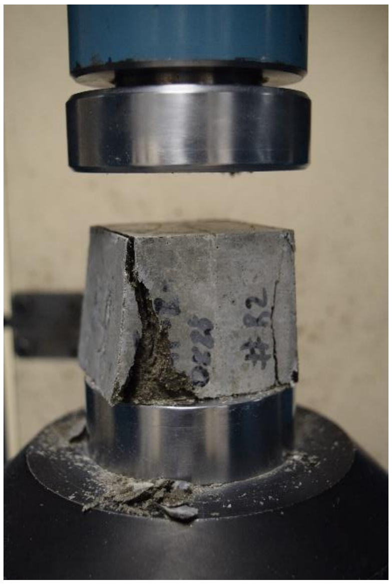
UAF-1128-7

UAF-1128-8

UAF-1128-9



UAF-1128-R1



UAF-1128-R2

UAF-1128-R3

E.4.3 Round 4 Batch 120518

E.4.3.1 3-Day Test (12/08/18)

UAF-1205-1

UAF-1205-2

UAF-1205-3

E.4.3.2 7-Day Test (12/12/18)

UAF-1205-4

UAF-1205-5

UAF-1205-6

E.4.3.3 28-Day Test (01/02/19)

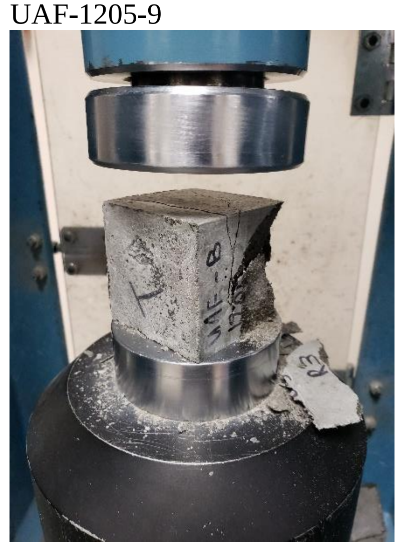
UAF-1205-7

UAF-1205-8

UAF-1205-9

UAF-1205-R1

UAF-1205-R2



UAF-1205-R3

E.4.4 Round 4 Batch 021819

E.4.4.1 3-Day Test (02/21/19)

UAF-0218-A1

UAF-0218-A2

UAF-0218-A3

UAF-0218-B1

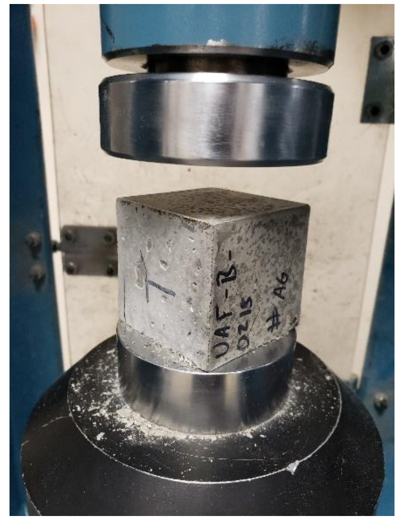
UAF-0218-B2

UAF-0218-B3

E.4.4.2 7-Day Test (02/25/19)

UAF-0218-A4

UAF-0218-A5



UAF-0218-A6

UAF-0218-B4

UAF-0218-B5

UAF-0218-B6

E.4.4.3 28-Day Test (03/18/19)


UAF-0218-A7


UAF-0218-A8


UAF-0218-A9


UAF-0218-A10


UAF-0218-A11


UAF-0218-A12


UAF-0218-B7


UAF-0218-B8


UAF-0218-B9


UAF-0218-B10


UAF-0218-B11


UAF-0218-B12

E.4.5 Round 4 Batch 031919

E.4.5.1 1-Day Test (03/20/19)


UAF-0319-A1


UAF-0319-A2


UAF-0319-A3


UAF-0319-B1


UAF-0319-B2


UAF-0319-B3

E.4.5.2 3-Day Test (03/22/19)

UAF-0319-A4

UAF-0319-A5

UAF-0319-A6


UAF-0319-B4

UAF-0319-B5

UAF-0319-B6

E.4.5.3 7-Day Test (03/26/19)

UAF-0319-A7

UAF-0319-A8

UAF-0319-A9

UAF-0319-B7

UAF-0319-B8

UAF-0319-B9

E.4.5.4 28-Day Test (04/16/19)

UAF-0319-A10

UAF-0319-A11

UAF-0319-A12

UAF-0319-B10

UAF-0319-B11

UAF-0319-B12

E.4.6 Round 4 Batch 032119

E.4.6.1 1-Day Test (03/22/19)

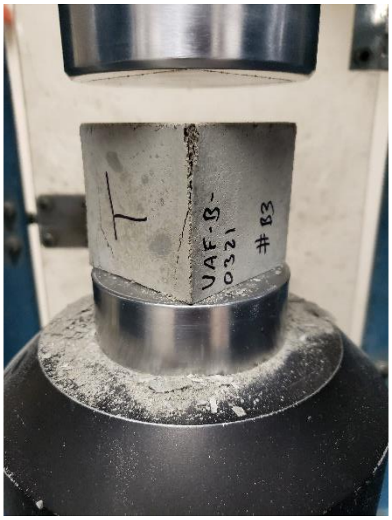
UAF-0321-A1

UAF-0321-A2

UAF-0321-A3

UAF-0321-B1

UAF-0321-B2



UAF-0321-B3

E.4.6.2 3-Day Test (03/24/19)

UAF-0321-A4

UAF-0321-A5

UAF-0321-A6

UAF-0321-B4

UAF-0321-B5

UAF-0321-B6

E.4.6.3 7-Day Test (03/28/19)


UAF-0321-A7

UAF-0321-A8

UAF-0321-A9

UAF-0321-B7


UAF-0321-B8


UAF-0321-B9

E.4.6.4 28-Day Test (04/18/19)


UAF-0321-A10


UAF-0321-A11


UAF-0321-A12


UAF-0321-B10


UAF-0321-B11


UAF-0321-B12

E.4.7 Round 4 Batch 041519

E.4.7.1 1-Day Test (04/16/19)

UAF-0415-A1

UAF-0415-A2

UAF-0415-A3

UAF-0415-B1

UAF-0415-B2

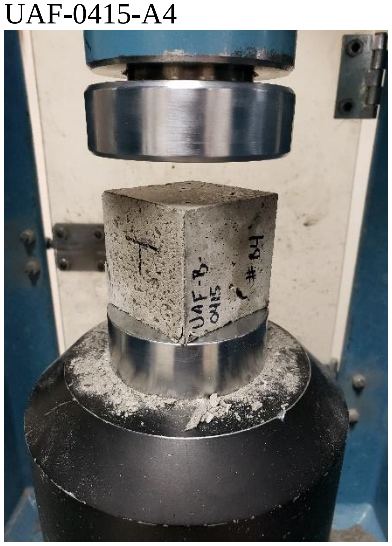
UAF-0415-B3

E.4.7.2 3-Day Test (04/18/19)

UAF-0415-A4

UAF-0415-A5

UAF-0415-A6



UAF-0415-B4

UAF-0415-B5

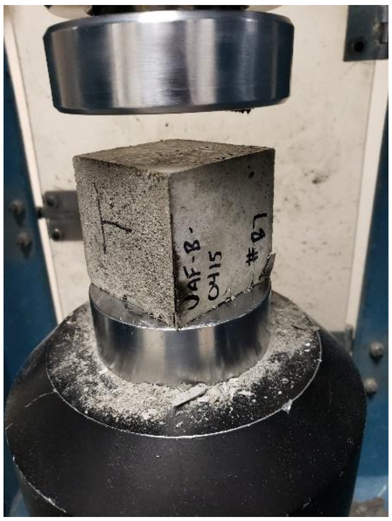
UAF-0415-B6

E.4.7.3 7-Day Test (04/22/19)

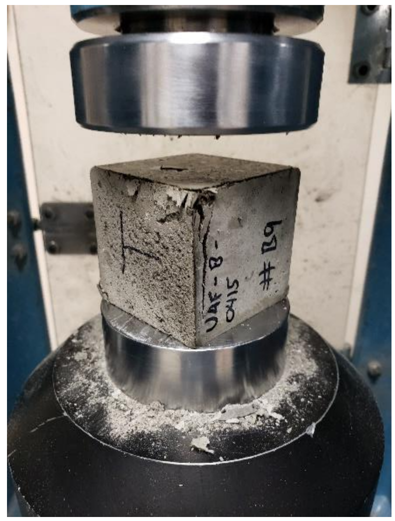

UAF-0415-A7


UAF-0415-A8


UAF-0415-A9


UAF-0415-B7


UAF-0415-B8


UAF-0415-B9

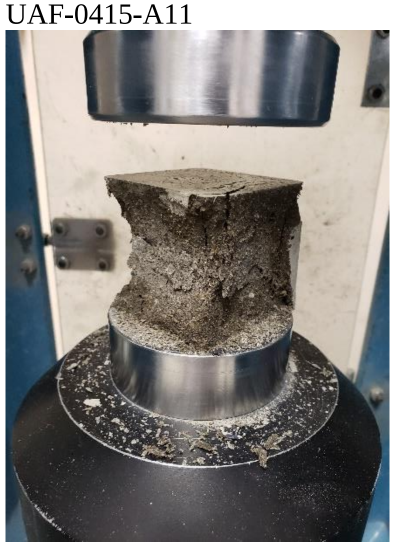
E.4.7.4 28-Day Test (05/13/19)


UAF-0415-A10


UAF-0415-A11


UAF-0415-A12


UAF-0415-B10


UAF-0415-B11


UAF-0415-B12

E.4.8 Round 4 Batch 042219

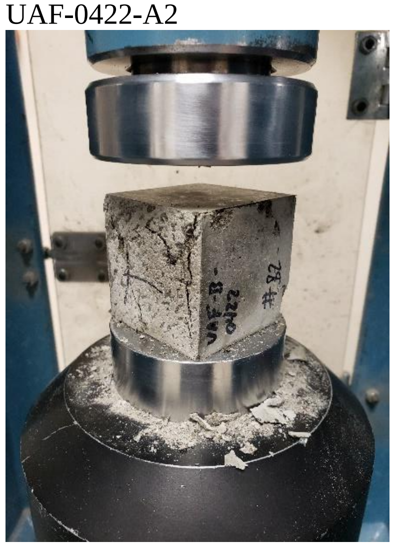
E.4.8.1 3-Day Test (04/25/19)

UAF-0422-A1

UAF-0422-A2

UAF-0422-A3

UAF-0422-B1



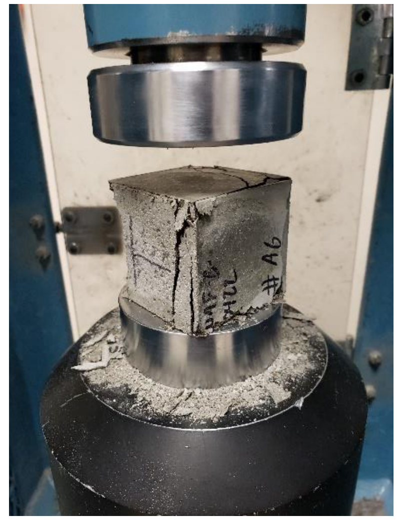
UAF-0422-B2

UAF-0422-B3

E.4.8.2 7-Day Test (04/29/19)


UAF-0422-A4


UAF-0422-A5


UAF-0422-A6


UAF-0422-B4

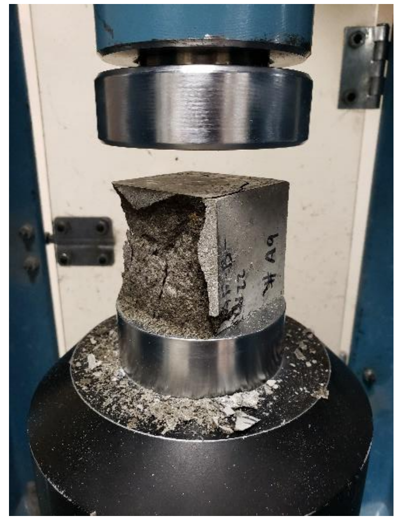

UAF-0422-B5


UAF-0422-B6

E.4.8.3 28-Day Test (05/20/19)


UAF-0422-A7


UAF-0422-A8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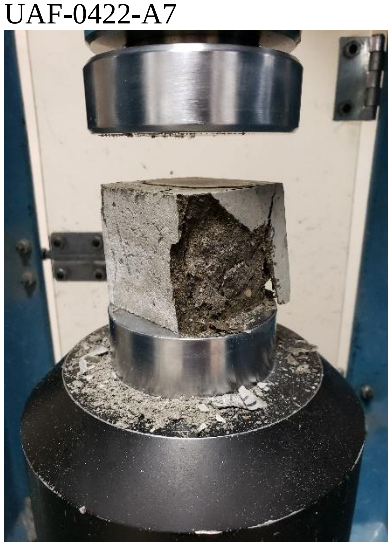
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UAF-0422-B7


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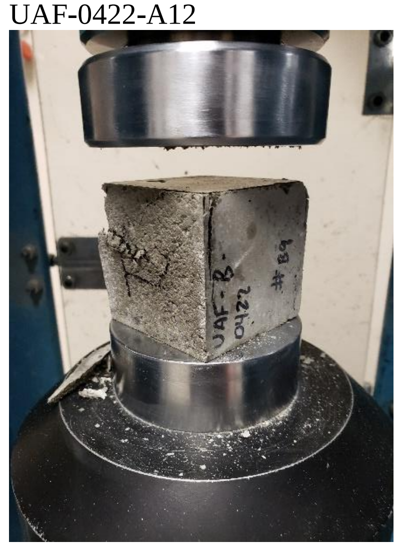
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UAF-0422-B12

E.5 Round 5

E.5.1 Round 5 Batch 060419

E.5.1.1 3-Day Test (06/07/19)


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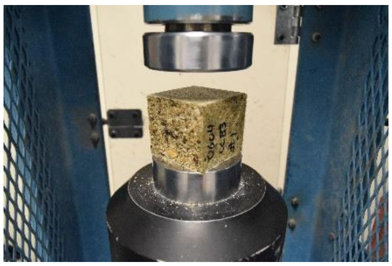
PPC-0604-A2


PPC-0604-A3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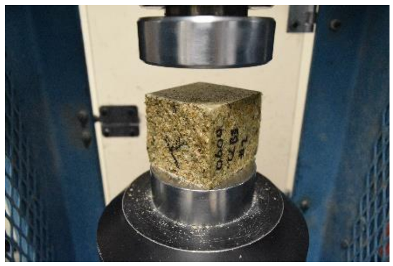
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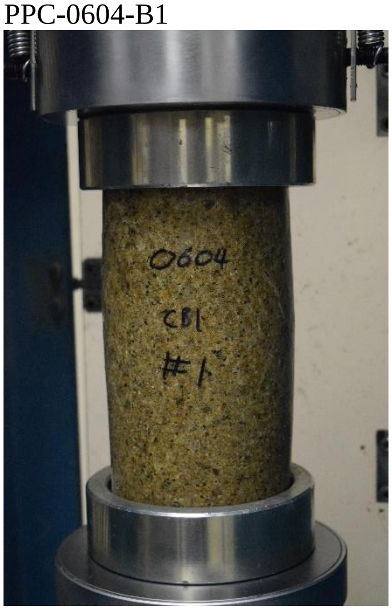

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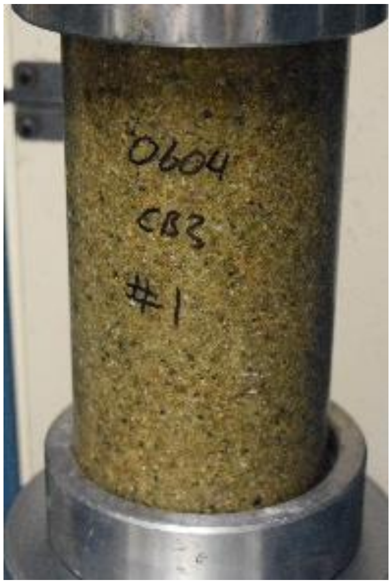

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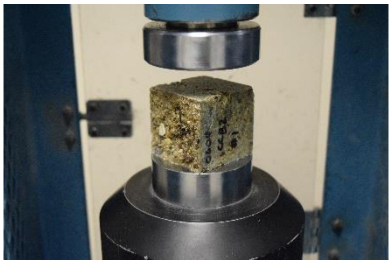
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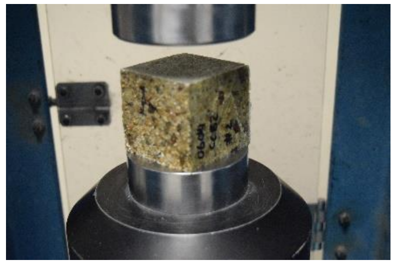
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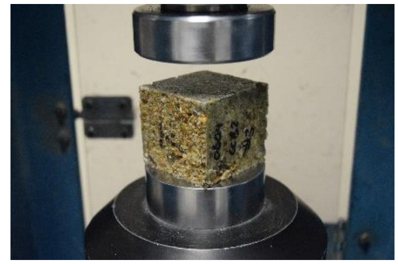
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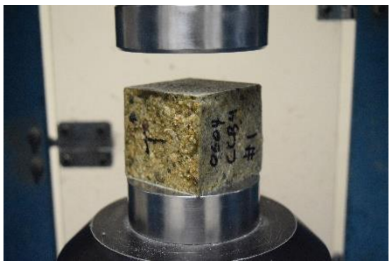
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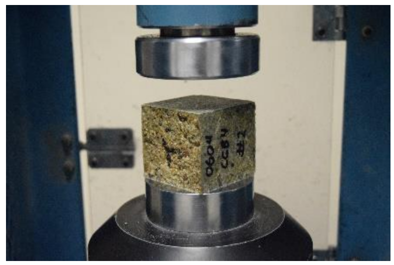
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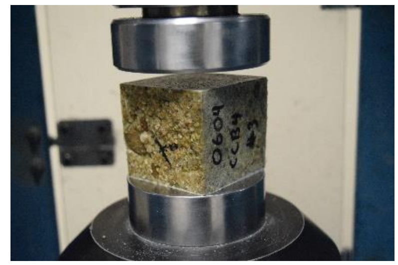
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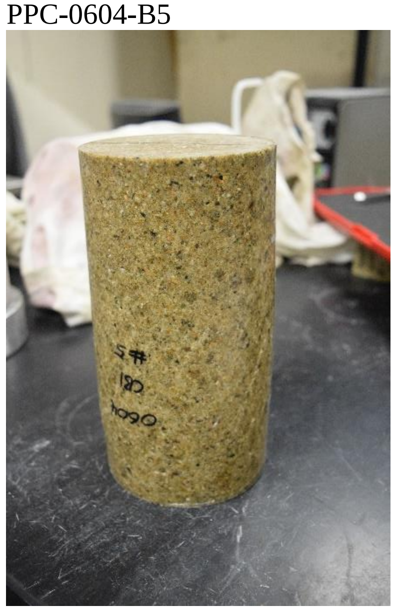
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PPC-0604-C-B5


PPC-0604-C-B6


PPC-0604-S-A1


PPC-0604-S-A2


PPC-0604-S-A3


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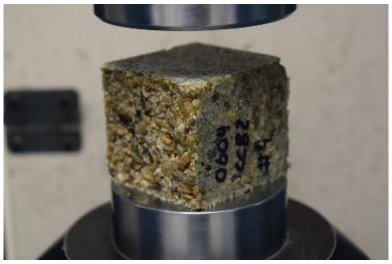
PPC-0604-S-B2


PPC-0604-S-B3

E.5.1.3 28-Day Test (07/02/19)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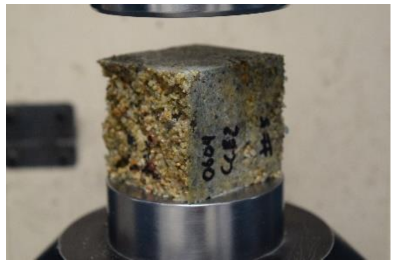
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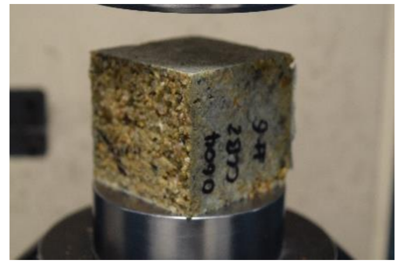
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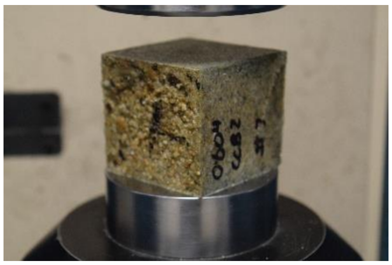
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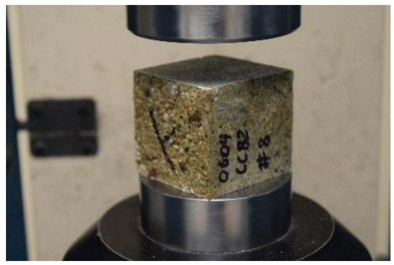
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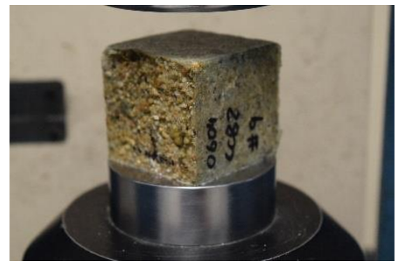
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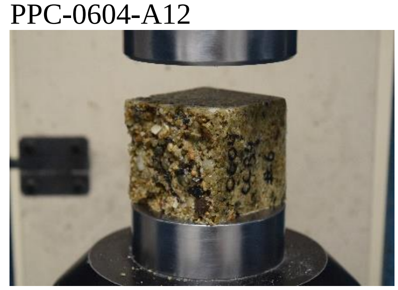
PPC-0604-B7


PPC-0604-B8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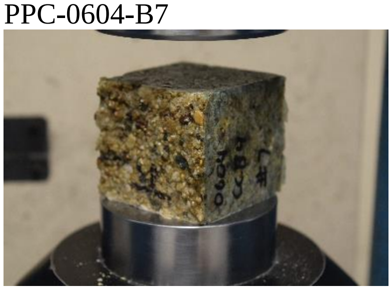
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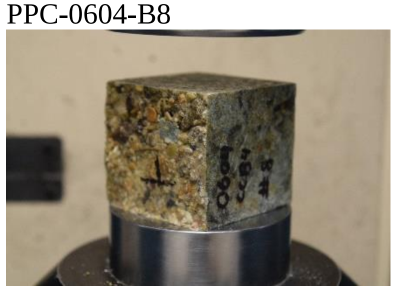
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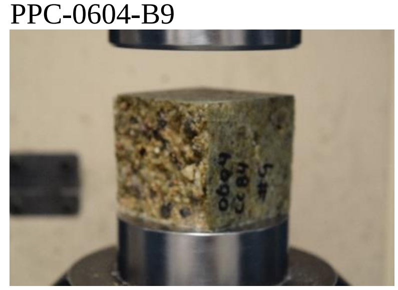
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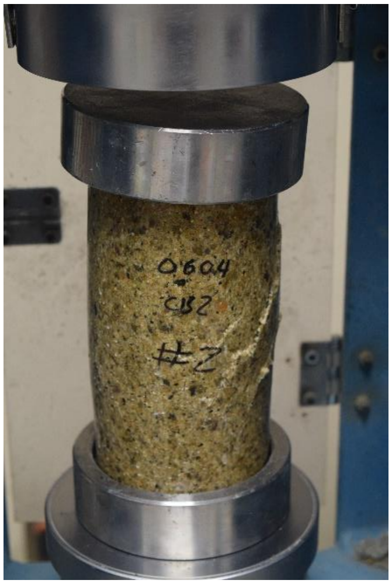

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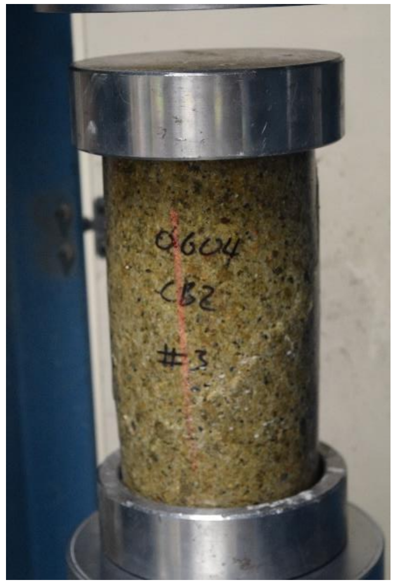

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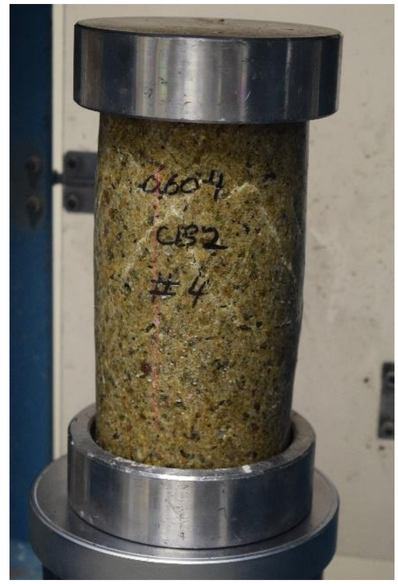

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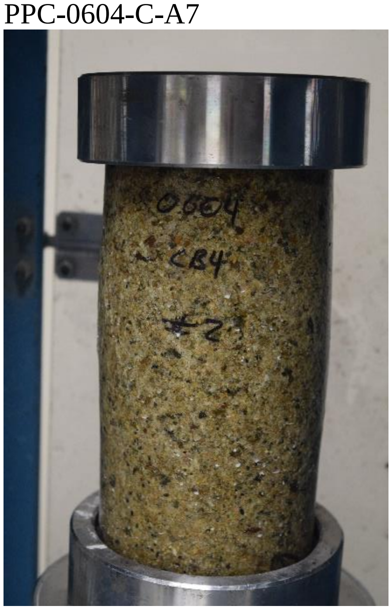

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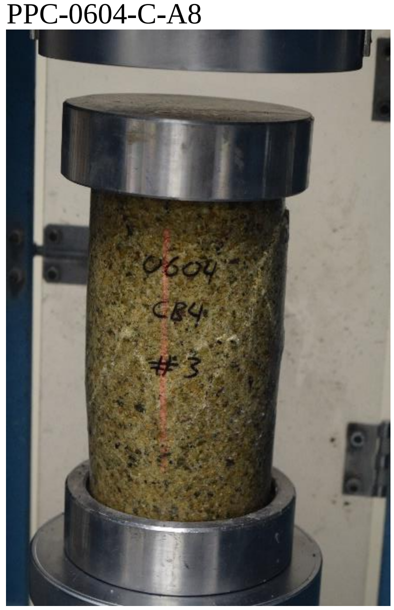

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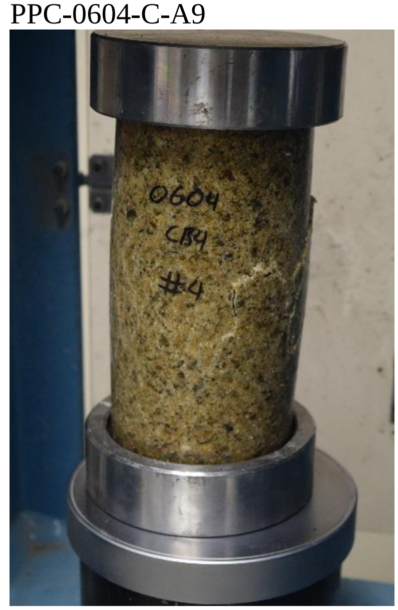

PPC-0604-C-B9


PPC-0604-S-A4


PPC-0604-S-A5


PPC-0604-S-A6


PPC-0604-S-A7


PPC-0604-S-A8


PPC-0604-S-A9


PPC-0604-S-B4


PPC-0604-S-B5


PPC-0604-S-B6


PPC-0604-S-B7


PPC-0604-S-B8


PPC-0604-S-B9

APPENDIX F.

MANUFACTURERS' SPECIFICATIONS OF SELECTED GROUT MATERIALS USED IN ALASKA PROJECTS

PRECISION NON-SHRINK GROUT

The Pro's Choice Since 1936

Sakrete® Precision Non-Shrink Construction Grout is a non-shrink and non-metallic. When properly mixed to a fluid consistency allows for pumping grout to areas where it is difficult to access using conventional grouting methods.

Features:

- Meets or exceeds ASTM C1107
- Non-corrosive, will not attack reinforcement
- Non-shrink
- Non-metallic, Non-staining
- High strength
- Pumpable for easy placement
- Meets Corps of Engineers Specification CRD-C 621

Use For:

Structural grouting and general purpose structural grouting:

- For use above, at or below grade
- Column bases
- Anchor bolts
- Machinery bases sole plates
- Tilt-up panels
- Steel bearing plates
- Reinforcing steel in block cells
- Dowel rods
- Transfer lines
- Concrete - poured in place, precast, tilt-up and prestressed

Yield/Water/Coverage:

Bag Size	Coverage	Water
50 lb (22.7 kg)	0.45 ft³ (12.7 L)	Fluid: 1 gal + 1 pt (4.3 L) Flowable: 1 gal (3.8 L) Plastic: 3 qts + 1 pt (3.3 L)

NOTE: Yield and water are approximate. The yield above does not allow for waste and spillage.

Color:

Gray

Technical Data:

DIVISION 9
Non-shrink Grouting
03 62 00

Technical Data cont.:

Precision Non-Shrink Grout	Fluid	Flowable	Plastic
Bag size	50 lb (22.7 kg)	50 lb (22.7 kg)	50 lb (22.7 kg)
Approx. water content per bag	1 gal + 1 pt (4.3 L)	1 gal (3.8 L)	3 qts + 1 pt (3.3 L)
Flow, ASTM C939	20-30 seconds		
Flow, at 5 drops, ASTM C1437		125-145	100-125
Compressive strength, ASTM C109			
24 hours	2,500 psi (17.3 MPa)	3,500 psi (24.2 MPa)	3,500 psi (24.2 MPa)
7 days	6,000 psi (41.4 MPa)	8,500 psi (58.7 MPa)	9,000 psi (62.1 MPa)
28 days	8,000 psi (55.2 MPa)	10,500 psi (72.3 MPa)	12,500 psi (86.2 MPa)
C-827 expansion	0 - 0.4	0 - 0.4	0 - 0.4
Height change, ASTM C1090			
1, 3, 7 and 28 days	0 - 0.2	0 - 0.2	0 - 0.2

NOTE: Test results obtained under controlled laboratory conditions at 73°F (23°C) and 50% humidity. More or less water may be required to achieve the desired mixing consistency depending on the atmospheric conditions and job site conditions. Do not exceed 4.75 qts (4.5 L) water per 50 lb (22.7 kg) bag.

Preparation/Application:

Refer to:

- ACI 302.1 Guide for Concrete Flooring and Slab Construction
- ACI 304.1 Guide for Measuring, Mixing, Transportation and Placing Concrete.

NOTE: it is the responsibility of the installer/applicator to ensure the suitability of the product for its intended use.

1. Use only when the product, air, and surface temperature are above 40°F (4°C) for a minimum of 24 hours.
2. Clean area and remove all unsound concrete, grease, oil, paint, and any other foreign material that will inhibit performance.
3. Prior to grout placement, all surfaces must be clean and saturated with water for 24 hours. Remove excess water bringing it to a surface saturated dry condition (SSD).
4. Provide air relief holes where necessary if grouting is beneath large plates.
5. Wood form work or other absorbent forms should be coated with a form release oil to prevent grout adherence and water absorption.
6. Design form work to facilitate rapid, continuous and complete filling of the space to be grouted. Rodding the grout lightly will help move material.
7. Use methods that will enable the grout to flow by gravity between the surfaces and keep the grout in full contact with these surfaces until it has hardened.

8. Avoid vibration which can cause bleeding and segregation. Shut down nearby machines for a minimum of 24 hours.
9. Minimum application thickness is 1" (25 mm) and a maximum thickness of 4" (100 mm).

NOTE: For installation where acids and sulfates are present, a protective coating is required. Protect uncoated aluminum from direct contact with Portland cement-based materials.

Refer to:
1. ACI 351. R-99 Report on Grouting Between Foundations and Bases for Support Equipment and Machinery
2. ACI 351.2R Foundations for Static Equipment
3. ACI 306R Cold Weather Concreting
4. ACI 305R Hot Weather Concreting

Mixing:
Desired grout consistency:
Fluid: 1 gal + 1 pt (4.3 L) per 50 lb (22.7 kg)
Flowable: 1 gal (3.8 L) per 50 lb (22.7 kg)
Plastic: 3 qts + 1 pt (3.3 L) per 50 lb (22.7 kg)

1. Only mix with clean potable water. The water quantities shown are approximate and may vary slightly with the type of equipment and application conditions.
2. Water demand and mix temperature must be determined using standard test methods for consistency and temperature measurement at the time of application.
3. Place 3/4 of desired mixing water, start mixer then slowly add the dry material. After all of the powder has been added, slowly add the remaining 1/4 water until the desired consistency is achieved.
4. Avoid adding excessive amounts of water that promotes segregation or bleeding of the grout.
5. Mix for 3 - 5 minutes to ensure a uniform lump free consistency and place immediately.

Curing:
1. Sakrete Construction Grout can be exposed under normal weathering conditions.
2. Forms may be removed as soon as the grout reaches its final set.
3. Prevent rapid water loss by covering the exposed grout surfaces with wet burlap during the first 48 hours or apply an acceptable water based cure and seal agent.
4. Protect from freezing for a minimum of 48 hours after placement. ACI 308 Standard Practice for Curing Concrete.

Precautions:
Air, mix and substrate temperatures should be between 40°F (4°C) and 100°F (38°C).

- Colder temperatures or higher humidity conditions will retard set times.
- Do not use in applications of high dynamic loading.
- Do not retemper grout by adding water.
- Do not use as a floor topping or in large areas with an exposed shoulder around base plates.

- Do not add accelerators, retarders, plasticizer or other additives.
- Do not apply in application thicknesses <1" (25 mm) or > than 4" (100 mm).

NOTE: Proper application and installation of all Sakrete products are the responsibility of the end user.

Safety:
READ and UNDERSTAND the Safety Data Sheet (SDS) before using this product. WARNING: Wear protective clothing and equipment. For emergency information, call CHEMTREC at 800-424-9300 or 703-527-3887 (outside USA).
KEEP OUT OF REACH OF CHILDREN.

Limited Product Warranty:
The manufacturer warrants that this product shall be of merchantable quality when used or applied in accordance with the manufacturer's instructions. This product is not warranted as suitable for any purpose other than the general purpose for which it is intended. This warranty runs for one (1) year from the dates the product is purchased. ANY IMPLIED WARRANTY OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE ON THIS PRODUCT IS LIMITED TO THE DURATION OF THIS WARRANTY. Liability under this warranty is limited to replacement or defective products or, at the manufacturer's option, refund of the purchase price. CONSEQUENTIAL AND INCIDENTAL DAMAGES ARE NOT RECOVERABLE UNDER THIS WARRANTY.

DESCRIPTION
The 1107 Advantage Grout is a non-shrink, non-metallic, non-corrosive, cementitious grout that is designed to provide a controlled, positive expansion to ensure an excellent bearing area. The 1107 Advantage Grout can be mixed from a fluid to a dry pack consistency.

USE
Exterior grouting of structural column base plates, pump and machinery bases, anchoring bolts, dowels, bearing pads and keyway joints. It finds applications in paper mills, oil refineries, food plants, chemical plants, sewage and water treatment plants etc.

FEATURES
- Controlled, net positive expansion
- Non shrink
- Non metallic/non corrosive
- Pourable, pumpable or dry pack consistency
- Interior/exterior applications

PROPERTIES
Corps of Engineers Specification for non-shrink grout:

CRD-C 621 Grades A, B, C

ASTM C-1107 Grades A, B, C

ASTM C-827 - 1107 Advantage Grout yielded a controlled positive expansion

Expansion - ASTM C-1090:

1 day: 0.10%

3 days: 0.11%

14 days: 0.11%

28 days: 0.11%

Test Results

	@ 1 Day		@ 3 Days		@ 7 Days		@ 28 Days	
Fluidity	PSI	MPa	PSI	MPa	PSI	MPa	PSI	MPa
Dry-Pack	5000	34.5	7000	48.2	9000	62.0	10000	68.9
Flowable	2500	17.2	5000	34.5	6000	41.4	8000	55.1
Fluid	2000	13.8	4000	27.6	5000	34.5	7500	51.7

Note:
The data shown is typical for controlled laboratory conditions. Reasonable variation from these results can be expected due to interlaboratory precision and bias. When testing the field mixed material, other factors such as variations in mixing, water content, temperature and curing conditions should be considered.

Estimating Guide
Yield (Flowable Consistency):
0.43 cu. ft./50 lbs. (0.0122 cu. m/22.7 kg) bag
0.59 cu. ft./50 lbs. (0.017 cu. m/22.7 kg) bag extended with 25 lbs. (11.34 kg) of washed 3/8 in. (1cm) pea gravel

Packaging

PRODUCT CODE	PACKAGE	SIZE	
		lbs	kg
67435	Bag	50	22.67
67437	Supersack	3,000	1,360.78

STORAGE
Store in a cool, dry area free from direct sunlight. Shelf life of unopened bags, when stored in a dry facility, is 12 months. Excessive temperature differential and /or high humidity can shorten the shelf life expectancy.

APPLICATION

Surface Preparation:
Thoroughly clean all contact surfaces. Existing concrete should be strong and sound. Surface should be roughened to insure bond. Metal base plates should be clean and free of oil and other contaminants. Maintain contact areas between 45°F (7°C) and 90°F (32°C) before grouting and during curing period.

Thoroughly wet concrete contact area 24 hours prior to grouting, keep wet and remove all surface water just prior to placement. If 24 hours is not possible, then saturate with water for at least 4 hours. Seal forms to prevent water or grout loss. On the placement side, provide an angle in the form high enough to assist in grouting and to maintain head pressure on the grout during the entire grouting process. Forms should be at least 1 in. (2.5 cm) higher than the bottom of the base plate.

Water Requirements:
Desired Mix Water / 50 lbs. (22.67 kg) Bag
Dry Pack: 5 pints (2.4 L)
Flowable: 8 pints (3.8 L)
Fluid: 9 pints (4.2 L)

Mixing:
A mechanical mixer with rotating blades like a mortar mixer is best. Small quantities can be mixed with a drill and paddle. When mixing less than a full bag, always first agitate the bag thoroughly so that a representative sample is obtained.

Place approximately 3/4 of the anticipated mix water into the mixer and add the grout mix, adding the minimum additional water necessary to achieve desired consistency.
Mix for a total of five minutes ensuring uniform consistency. For placements greater in depth than 3 in. (7.6 cm), up to 25 lbs. (11.34 kg) of washed 3/8 in. (1 cm) pea gravel must be added to each 50 lbs. (22.7 kg) bag of grout. The approximate working time (pot life) is 30 minutes but will vary somewhat with ambient conditions.

For hot weather conditions, greater than 85°F (29°C), mix with cold water approximately 40°F (4°C).
For cold weather conditions, less than 50°F (10°C), mix with warm water, approximately 90°F (29°C). For additional hot and cold weather applications, contact Dayton Superior.

Placement:

Grout should be placed preferably from one side using a grout box to avoid entrapping air. Grout should not be over-worked or over-watered causing segregation or bleeding. Vent holes should be provided where necessary.
When possible, grout bolt holes first. Placement and consolidation should be continuous for any one section of the grout. When nearby equipment causes vibration of the grout, such equipment should be shut down for a period of 24 hours. Forms may be removed when grout is completely self-supporting. For best results, grout should extend downward at a 45 degree angle from the lower edge of the steel base plates or similar structures.

CLEAN UP

Use clean water. Hardened material will require mechanical removal methods.

CURING

Exposed grout surfaces must be cured. Dayton Superior recommends using a Dayton Superior curing compound, cure & seal or a wet cure for 3 days. Maintain the temperature of the grout and contact area at 45°F (7°C) to 90°F (32°C) for a minimum of 24 hours.

LIMITATIONS

FOR PROFESSIONAL USE ONLY

Do not re-temper after initial mixing
Do not add other
cements or additives
Setting time for the 1107 Advantage Grout will slow during cooler weather, less than 50°F (10°C) and speed up during hot weather, greater than 80°F (27°C)
Prepackaged material segregates while in the bag, thus when mixing less than a full bag it is recommended to first agitate the bag to assure it is blended prior to sampling.

PRECAUTIONS

READ SDS PRIOR TO USING PRODUCT

- Product contains Crystalline Silica and Portland Cement Avoid breathing dust Silica may cause serious lung problems
- Use with adequate ventilation
  n Wear protective clothing, gloves and eye protection (goggles, safety glasses and/or face shield)
- Keep out of the reach of children
- Do not take internally
- In case of ingestion, seek medical help immediately
- May cause skin irritation upon contact, especially prolonged or repeated. If skin contact occurs, wash immediately with soap and water and seek medical help as needed.
- If eye contact occurs, flush immediately with clean water and seek medical help as needed
- Dispose of waste material in accordance with federal, state and local requirements

MANUFACTURER

Dayton Superior Corporation
1125 Byers Road
Miamisburg, OH 45342
Customer Service: 888-977-9600
Technical Services: 877-266-7732
Website: www.daytonsuperior.com

WARRANTY

Dayton Superior Corporation ("Dayton") warrants for 12 months from the date of manufacture or for the duration of the published product shelf life, whichever is less, that at the time of shipment by Dayton, the product is free of manufacturing defects and conforms to Dayton's product properties in force on the date of acceptance by Dayton of the order. Dayton shall only be liable under this warranty if the product has been applied, used, and stored in accordance with Dayton's instructions, especially surface preparation and installation, in force on the date of acceptance by Dayton of the order. The purchaser must examine the product when received and promptly notify Dayton in writing of any non-conformity before the product is used and no later than 30 days after such non-conformity is first discovered. If Dayton, in its sole discretion, determines that the product breached the above warranty, it will, in its sole discretion, replace the non-conforming product, refund the purchase price or issue a credit in the amount of the purchase price. This is the sole and exclusive remedy for breach of this warranty. Only a Dayton officer is authorized to modify this warranty. The information in this data sheet supersedes all other sales information received by the customer during the sales process. THE FOREGOING WARRANTY SHALL BE EXCLUSIVE AND IN LIEU OF ANY OTHER WARRANTIES, EXPRESS OR IMPLIED, INCLUDING WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE, AND ALL OTHER WARRANTIES OTHERWISE ARISING BY OPERATION OF LAW, COURSE OF DEALING, CUSTOM, TRADE OR OTHERWISE.

TECHNICAL DATA SHEET

Dayton shall not be liable in contract or in tort (including, without limitation, negligence, strict liability or otherwise) for loss of sales, revenues or profits; cost of capital or funds; business interruption or cost of downtime, loss of use, damage to or loss of use of other property (real or personal); failure to realize expected savings; frustration of economic or business expectations; claims by third parties (other than for bodily injury), or economic losses of any kind; or for any special, incidental, indirect, consequential, punitive or exemplary damages arising in any way out of the performance of, or failure to perform, its obligations under any contract for sale of product, even if Dayton could foresee or has been advised of the possibility of such damages. The Parties expressly agree that these limitations on damages are allocations of risk constituting, in part, the consideration for this contract, and also that such limitations shall survive the determination of any court of competent jurisdiction that any remedy provided in these terms or available at law fails of its essential purpose.

DAYTON® SUPERIOR®

Sure-Grip® High Performance Grout

Cement-Based Grout

TECHNICAL DATA SHEET

DESCRIPTION

Sure-Grip High Performance Grout is a non-shrink, non-corrosive, non-metallic cementitious grout designed to provide a controlled, positive expansion and to ensure an excellent bearing area. Sure-Grip High Performance Grout can be mixed in a fluid or flowable consistency.

USE

Sure-Grip High Performance Grout is an ideal product for interior or exterior grouting of architectural and structural precast concrete components, structural column base plates, machinery bases, anchoring bolts, cable anchorages, dowels, bearing pads, keyway joints, crane rails or anywhere a high quality engineered grout is required.

FEATURES

- High compressive strength quickly – 5,000 psi in one day
- Less downtime for machines/finish projects sooner
- High ultimate compressive strength – 10,000 psi in 28 days
- Non-metallic/non corrosive
- High density
- Low water requirements
- High fluidity/pourable/pumpable
- Interior/exterior applications
- Approved by numerous state DOTs
- Tested and Certified by WQA to NSF/ANSI 61

PROPERTIES

Corps of Engineers Specification for non-shrink grout: CRD-C 621, Grades A, B and C

ASTM C-1107: Specification for non-shrink grout Grades A, B and C

ASTM C-827: Sure-Grip Grout yielded a controlled positive expansion Expansion

(ASTM C-1090):
1 day-0-0.3

3 days-0-0.3

14 days-0-0.3

28 days-0-0.3

Test Results

	@ 1 Day		@ 3 Days		@ 7 Days		@28 Days	
Fluidity	PSI	MPa	PSI	MPa	PSI	MPa	PSI	MPa
Drypack	10,500	72.3	10,750	74.1	11,000	75.8	12,500	86.1
Flowable	6,000	41.3	8,000	55.1	8,200	56.5	10,000	68.9
Fluid	4,500	31.1	6,500	44.8	7,000	48.2	9,000	62.0

Note:
The data shown is typical for controlled laboratory conditions. Reasonable variation from these results can be expected due to interlaboratory precision and bias. When testing the field mixed material, other factors such as variations in mixing, water content, temperature and curing conditions should be considered.

Estimating Guide

Yield (flowable consistency): 0.42 cu. ft./50 lbs. (0.011 cu. m/22.7 kg) bag 0.57 cu. ft./per 50 lbs. (0.015 cu. m/22.7 kg) extended with 25 lbs. (11.34 kg) of washed 3/8 in. (1 cm) pea gravel

Packaging

PRODUCT CODE	PACKAGE	SIZE	
		lbs	kg
67440	Bag	50	22.67
122964	Supersack	3,000	1,360.77

STORAGE

Store in a cool, dry area free from direct sunlight. Shelf life of unopened bags, when stored in a dry facility is 12 months. Excessive temperature differential and /or high humidity can shorten the shelf life expectancy.

Surface Preparation:
Thoroughly clean all contact surfaces. Existing concrete should be strong and sound. Surface should be roughened to insure bond.
Metal base plates should be clean and free of oil and other contaminants.
Maintain contact areas between 45°F (7°C) and 90°F (32°C) before grouting and during curing period.
Thoroughly wet concrete contact area 24 hours prior to grouting. keep wet and remove all surface water just prior to placement. If 24 hours is not possible, then saturate with water for at least 4 hours. Seal forms to prevent water or grout loss. On the placement side, provide an angle in the form high enough to assist in grouting and to maintain head pressure on the grout during the entire grouting process.
Forms should be at least 1 in. (2.5 cm) higher than the bottom of the base plate.

Water Requirements:
Water per 50 lbs. (22.7 kg) Bag
Drypack 2.5 quarts (2.4 L)
Flowable 3.25 quarts (3.1 L)
Fluid 4.00 quarts (3.8 L)

Mixing:
A mechanical mixer with rotating blades like a mortar mixer is best. Small quantities can be mixed with a drill and paddle. When mixing less than a full bag, always first agitate the bag thoroughly so that a representative sample is obtained. Place approximately 3/4 of the anticipated mix water into the mixer and add the grout mix, adding the minimum additional water necessary to achieve desired consistency. Mix for a total of five minutes to ensure uniform consistency. For placements greater than 3 in. (7.6 cm), up to 25 lbs. (11.34 kg) of washed 3/8 in. (1 cm.) pea gravel must be added to each 50 lb. (22.7 kg) bag of grout. The approximate working time (pot life) is 30 minutes but will vary with ambient conditions.

For hot weather conditions (greater than 85°F [29°C]) mix with cold water (approximately 40°F [4°C]). For cold weather conditions (less than 50°F [10°C]) mix with warm water (approximately 90°F [29°C]). For additional hot and cold weather applications, contact Dayton Superior.

Placement:
Grout should be placed preferably from one side using a grout box to avoid entrapped air pockets. Grout should not be over worked which causes segregation. Provide vent holes where necessary. Forms must be sealed to prevent water or grout loss. When possible, grout bolt holes first. Placement and consolidation should be continuous for any one section of the grout. When nearby equipment causes vibration of the grout, such equipment should be shut down for a period of 24 hours (@73°F, 23°C). Forms may be removed when grout is completely selfsupporting. Cut away areas where grout excessively restricts movement of steel, i.e., edges of base plates, etc. For best results, grout should extend downward at a 45° angle from the lower edge of the steel base plates or similar structures.

CURING
Exposed grout surfaces must be cured. Dayton Superior recommends using a Dayton Superior curing compound, cure & seal or a wet cure for 3 days. Maintain the temperature of the grout and contact area at 45°F (7°C) to 90°F (32°C) for a minimum of 24 hours

CLEAN UP
Use clean water. Hardened material will require mechanical removal methods.

LIMITATIONS

FOR PROFESSIONAL USE ONLY
Do not re-temper after initial mixing.
Do not add other cements or additives.
Setting time for the Sure-Grip High Performance Grout will slow during cooler weather, less than 50°F (10°C) and speed up during hot weather, greater than 80°F (27°C).
Prepackaged material segregates while in the bag, thus when mixing less than a full bag it is recommended to first agitate the bag to assure it is blended prior to sampling.

PRECAUTIONS

READ SDS PRIOR TO USING PRODUCT
- Product contains Crystalline Silica and Portland Cement – Avoid breathing dust – Silica may cause serious lung problems
- Use with adequate ventilation
- Wear protective clothing, gloves and eye protection (goggles, safety glasses and/or face shield)
- Keep out of the reach of children

- Do not take internally
- In case of ingestion, seek medical help immediately
- May cause skin irritation upon contact, especially prolonged or repeated. If skin contact occurs, wash immediately with soap and water and seek medical help as needed.
- If eye contact occurs, flush immediately with clean water and seek medical help as needed
- Dispose of waste material in accordance with federal, state and local requirements

MANUFACTURER

Dayton Superior Corporation
1125 Byers Road
Miamisburg, OH 45342
Customer Service: 888-977-9600
Technical Services: 877-266-7732
Website: www.daytonsuperior.com

WARRANTY

Dayton Superior Corporation ("Dayton") warrants for 12 months from the date of manufacture or for the duration of the published product shelf life, whichever is less, that at the time of shipment by Dayton, the product is free of manufacturing defects and conforms to Dayton's product properties in force on the date of acceptance by Dayton of the order. Dayton shall only be liable under this warranty if the product has been applied, used, and stored in accordance with Dayton's instructions, especially surface preparation and installation, in force on the date of acceptance by Dayton of the order. The purchaser must examine the product when received and promptly notify Dayton in writing of any non-conformity before the product is used and no later than 30 days after such non-conformity is first discovered. If Dayton, in its sole discretion, determines that the product breached the above warranty, it will, in its sole discretion, replace the non-conforming product, refund the purchase price or issue a credit in the amount of the purchase price. This is the sole and exclusive remedy for breach of this warranty. Only a Dayton officer is authorized to modify this warranty. The information in this data sheet supersedes all other sales information received by the customer during the sales process. THE FOREGOING WARRANTY SHALL BE EXCLUSIVE AND IN LIEU OF ANY OTHER WARRANTIES, EXPRESS OR IMPLIED, INCLUDING WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE, AND ALL OTHER WARRANTIES OTHERWISE ARISING BY OPERATION OF LAW, COURSE OF DEALING, CUSTOM, TRADE OR OTHERWISE.

Dayton shall not be liable in contract or in tort (including, without limitation, negligence, strict liability or otherwise) for loss of sales, revenues or profits; cost of capital or funds; business interruption or cost of downtime, loss of use, damage to or loss of use of other property (real or personal); failure to realize expected savings; frustration of economic or business expectations; claims by third parties (other than for bodily injury), or economic losses of any kind; or for any special, incidental, indirect, consequential, punitive or exemplary damages arising in any way out of the performance of, or failure to perform, its obligations under any contract for sale of product, even if Dayton could foresee or has been advised of the possibility of such damages. The Parties expressly agree that these limitations on damages are allocations of risk constituting, in part, the consideration for this contract, and also that such limitations shall survive the determination of any court of competent jurisdiction that any remedy provided in these terms or available at law fails of its essential purpose.

We create chemistry

Technical Data Guide

3 | 03 62 13
Non-Metallic
Non-Shrink Grouting

MasterFlow® 928

High-precision mineral-aggregate grout with extended working time

PACKAGING
55 lb (25 kg) polyethylene-lined bags
3,300 lb (1,500 kg) bulk bags

YIELD
One 55 lb (25 kg) bag of MasterFlow 928 grout mixed with 10.5 lbs (4.8 kg) or 1.26 gallons (4.8 L) of water (fluid consistency) provides approximately 0.50 ft^3 (0.014 m^3) of grout.

Note: The water requirement may vary due to mixing efficiency, temperature, and other variables.

STORAGE
Store in unopened containers in cool, clean, dry conditions

SHELF LIFE
55 LB BAG: 1 year when properly stored
3,300 LB BULK BAG: 3 months when properly stored

VOC CONTENT
0 g/L less water and exempt solvents

DESCRIPTION
MasterFlow 928 grout is a hydraulic cement-based mineral aggregate non-shrink grout with extended working time. It is ideally suited for grouting machines or plates requiring precision load-bearing support. It can be placed from fluid to damp pack over a temperature range of 45 to 90° F (7 to 32° C).

PRODUCT HIGHLIGHTS
- Meets the requirements of ASTM C1107 and US Army Corps of Engineers CRD C621 (Grades B and C), at a fluid consistency over a 30-minute working time
- ANSI/NSF 61 certified for use with potable water
- Pumpable
- Extended working time
- Can be mixed at a wide range of consistencies
- Freeze/thaw resistant making it suitable for exterior applications
- Hardens free of bleeding, segregation, or settlement shrinkage to provide maximum effective bearing area for optimum load transfer
- Contains high-quality, well-graded quartz aggregate for optimum strength and workability
- Sulfate resistant for marine, wastewater and other sulfate-containing environments

APPLICATIONS
- Grouting of equipment, such as compressors and generators, pump bases and drive motors, tank bases, conveyors, etc.
- Grouting anchor bolts, rebar and dowel rods
- Grouting of precast wall panels, beams, columns, curtain walls, concrete systems and other structural and non-structural building components
- Repairing concrete, including grouting voids and rock pockets

SUBSTRATES
- Concrete

Technical Data

Composition

MasterFlow 928 is a hydraulic cement-based mineral-aggregate grout.

Compliances

- ASTM C 1107 and CRD 621, Grades B and C, requirements at a fluid consistency over a temperature range of 40–90° F (4–32° C)
- ANSI / NSF 61 for use with potable water

Test Data

PROPERTY		RESULTS		TEST METHOD
Compressive strengths, psi (MPa)				ASTM C 942, according to ASTM C 1107 of ASTM C 109
		Consistency		
	Plastic[1]	**Flowable**[2]	**Fluid**[3]	
1 day	4,500 (31)	4,000 (28)	3,500 (24)	
3 days	6,000 (41)	5,000 (34)	4,500 (31)	
7 days	7,500 (52)	6,700 (46)	6,500 (45)	
28 days	9,000 (62)	8,000 (55)	7,500 (52)	
Volume change				ASTM C 1090
	% Change	**% Requirement of ASTM C 1107**		
1 day	> 0	0.0 – 0.30		
3 days	0.04	0.0 – 0.30		
14 days	0.05	0.0 – 0.30		
28 days	0.06	0.0 – 0.30		
Setting time, hr:min				ASTM C 191
		Consistency		
	Plastic[1]	**Flowable**[2]	**Fluid**[3]	
Initial set	2:30	3:00	4:30	
Final set	4:00	5:00	6:00	
Flexural strength,* psi (MPa)				ASTM C 78
3 days		1,000 (6.9)		
7 days		1,050 (7.2)		
28 days		1,150 (7.9)		
Modulus of elasticity,* psi (MPa)				ASTM C 469, modified
3 days		2.82×10^6 (1.94×10^4)		
7 days		3.02×10^6 (2.08×10^4)		
28 days		3.24×10^6 (2.23×10^4)		
Coefficient of thermal expansion,* in/in/° F (cm/cm/° C)		6.5×10^{-6} (11.7×10^{-6})		ASTM C 531
Punching shear strength,* psi (MPa), 3 by 3 by 11" (76 by 76 by 279 mm) beam				BASF Method
3 days		2,200 (15.2)		
7 days		2,260 (15.6)		
28 days		2,650 (18.3)		
Split tensile and tensile strength,* psi (MPa)				ASTM C 496 (splitting tensile) ASTM C 190 (tensile)
		Splitting Tensile	**Tensile**	
3 days		575 (4.0)	490 (3.4)	
7 days		630 (4.3)	500 (3.4)	
28 days		675 (4.7)	500 (3.4)	
Resistance to rapid freezing and thawing, 300 Cycles		Durability Factor 99%		ASTM C 666, Procedure A

[1]100–125% flow on flow table per ASTM C 230
[2]125–145% flow on flow table per ASTM C 230
[3]25 to 30 seconds through flow cone per ASTM C 939
*Test conducted at a fluid consistency
This data was developed under controlled laboratory conditions. Expect reasonable variations

Test Data (continued)

PROPERTY	RESULTS			TEST METHOD
Ultimate tensile strength and bond stress				ASTM E 488, tests*
Diameter in (mm)	**Depth** in (mm)	**Tensile strength** lbs (kg)	**Bond stress** psi (MPa)	
5/8 (15.9)	4 (101.6)	23,500 (10,575)	2,991 (20.3)	
3/4 (19.1)	5 (127.0)	30,900 (13,905)	2,623 (18.1)	
1 (25.4)	6.75 (171.5)	65,500 (29,475)	3,090 (21.3)	

*Average of 5 tests in ≥ 4,000 psi (27.6 MPa) concrete, using 125 ksi threaded rod in 2” (51 mm) diameter, damp, core-drilled holes.

Notes

1. Grout was mixed to a fluid consistency.
2. Recommended design stress: 2,275 psi (15.7 MPa).
3. For more detailed information regarding anchor bolt applications, contact Technical Service.
4. Tensile tests with headed fasteners were governed by concrete failure.

Jobsite Testing

If strength tests must be made at the jobsite, use 2” (51 mm) metal cube molds as specified by ASTM C 942 and the ASTM C 1107 modification of ASTM C 109. DO NOT use cylinder molds. Control field and laboratory tests on the basis of desired placement consistency rather than strictly on water content.

HOW TO APPLY

SURFACE PREPARATION

1. Steel surfaces must be free of dirt, oil, grease, or other contaminants.
2. The surface to be grouted must be clean, SSD, strong, and roughened to a CSP of 5–9 following ICRI Guideline 310.2 to permit proper bond.
3. When dynamic, shear or tensile forces are anticipated, concrete surfaces should be chipped with a “chisel-point” hammer, to a roughness of (plus or minus) ⅜" (10 mm). Verify the absence of bruising following ICRI Guideline 210.3.
4. Concrete surfaces should be saturated (ponded) with clean water for 24 hours just before grouting.
5. All freestanding water must be removed from the foundation and bolt holes immediately before grouting.
6. Anchor bolt holes must be grouted and sufficiently set before the major portion of the grout is placed.
7. Shade the foundation from sunlight 24 hours before and 24 hours after grouting.

FORMING

1. Forms should be liquid tight and nonabsorbent. Seal forms with putty, sealant, caulk or polyurethane foam. Use sufficient bracing to prevent the grout from leaking or moving.
2. Moderately sized equipment should utilize a head box to enhance the grout placement.
3. Side and end forms should be a minimum 1" (25 mm) distant horizontally from the equipment to be grouted to permit expulsion of air and any remaining saturation water as the grout is placed.
4. Leave a minimum of 2" between the bearing plate and the form to allow for ease of placement.
5. Eliminate large, non-supported grout areas wherever possible.
6. Extend forms a minimum of 1" (25 mm) higher than the bottom of the equipment being grouted.
7. Expansion joints may be necessary. Consult your local BASF field representative for suggestions and recommendations.

TEMPERATURE

1. The ambient and initial temperature of the grout should be in the range of 45 to 90° F (7 to 32° C) for both mixing and placing. For precision grouting, store and mix grout to produce the desired mixed-grout temperature. If bagged material is hot, use cold water, and if bagged material is cold, use warm water to achieve a mixed-product temperature as close to 70° F (21°C) as possible.
2. If temperature extremes are anticipated or special placement procedures are planned, contact your local BASF representative for assistance.
3. When grouting at minimum temperatures, see that the foundation, plate, and grout temperatures do not fall below 40° F (7° C) until after final set. Protect the grout from freezing (32° F or 0° C) until it has attained a compressive strength of 3,000 psi (21 MPa) in accordance with ASTM C 109.

Recommended Temperature Guidelines for Precision Grouting

	MINIMUM ˚ F (˚ C)	PREFERRED ˚ F (˚ C)	MAXIMUM ˚ F (˚ C)
Foundation and plates	45 (7)	50–80 (10–27)	90 (32)
Mixing water	45 (7)	50–80 (10–27)	90 (32)
Grout at mixed and placed temp.	45 (7)	50–90 (10–27)	90 (32)

MIXING

By using the minimum amount of water to provide the desired workability, maximum strength will be achieved. Whenever possible, mix the grout with a mortar mixer or an electric drill with a paddle such as ICRI 320.5 type A, D, E, F, G or H. Put the measured amount of potable water into the mixer, add grout, then mix till a uniform consistency is attained. Do not use water in an amount or a temperature that will cause bleeding or segregation. Note: The water requirement may vary due to mixing efficiency, temperature, and other variables.

1. Place estimated water (use potable water only) into the mixer, then slowly add the grout. For a fluid consistency, start with 9 lbs (4 kg) (1.1 gallon [4.2L]) per 55 lb bag.
2. The water demand will depend on mixing efficiency, material, and ambient-temperature conditions. Adjust the water to achieve the desired flow. Recommended flow is 25–30 seconds using the ASTM C 939 Flow-Cone Method. Use the minimum amount of water required to achieve the necessary placement consistency.
3. Moderately sized batches of grout are best mixed in one or more clean mortar mixers. For large batches, use ready-mix trucks and 3,300 lb (1,500 kg) bags for maximum efficiency and economy.
4. Mix grout between 3 and 5 minutes after all material and water is in the mixer until a homogenous consistency is achieved. Use mechanical mixer only.
5. Do not mix more grout than can be placed in approximately 30 minutes.
6. Transport by wheelbarrow or buckets or pump to the equipment being grouted. Minimize the transporting distance.
7. Do not retemper grout by adding water and remixing after it stiffens.
8. Do not add plasticizers, accelerators, retarders, or other additives.
9. For placements greater than 6" (152 mm) in depth, product should be extended with aggregate. Aggregate extension is dependent upon the grout type, placement, application requirements, and is typically required for placement depths beyond the limitation of the neat material. The aggregate should be washed, graded, saturated, surface-dry (SSD), high-density, free from deleterious materials, and comply with the requirements of ASTM C 33. Consult BASF Technical Service for additional guidance.

PLACEMENT

1. Always place grout from only one side of the equipment to prevent air or water entrapment beneath the equipment. Place Masterflow 928 in a continuous pour. Discard grout that becomes unworkable. Make sure that the material fills the entire space being grouted and that it remains in contact with plate throughout the grouting process.
2. Immediately after placement, trim the surfaces with a trowel and cover the exposed grout with clean wet rags (not burlap). Keep rags moist until grout surface is ready for finishing or until final set.
3. The grout should offer stiff resistance to penetration with a pointed mason's trowel before the grout forms are removed or excessive grout is cut back. After removing the damp rags, immediately coat with a recommended curing compound compliant with ASTM C 309 or preferably ASTM C 1315.
4. Do not vibrate grout. Use steel straps inserted under the plate to help move the grout.
5. Minimum placement thickness is 1" (25 mm). Consult your BASF representative before placing lifts more than 6" (152 mm) in depth.

CURING

Cure all exposed grout with an approved membrane curing compound compliant with ASTM C 309 or preferably ASTM C 1315. Apply curing compound immediately after the wet rags are removed to minimize potential moisture loss.

WASTE DISPOSAL METHOD

This product when discarded or disposed of, is not listed as a hazardous waste in federal regulations. Dispose of in a landfill in accordance with local regulations. For additional information on personal protective equipment, first aid, and emergency procedures, refer to the product Safety Data Sheet (SDS) on the job site or contact the company at the address or phone numbers given below.

HEALTH, SAFETY AND ENVIRONMENTAL

Read, understand and follow all Safety Data Sheets and product label information for this product prior to use. The SDS can be obtained by visiting www.master-builders-solutions.basf.us, e-mailing your request to basfbscst@basf.com or calling 1(800)433-9517. Use only as directed.

For medical emergencies only, call ChemTrec® 1(800) 424-9300.

LIMITED WARRANTY NOTICE

BASF warrants this product to be free from manufacturing defects and to meet the technical properties on the current Technical Data Guide, if used as directed within shelf life. Satisfactory results depend not only on quality products but also upon many factors beyond our control. BASF MAKES NO OTHER WARRANTY OR GUARANTEE, EXPRESS OR IMPLIED, INCLUDING WARRANTIES OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE WITH RESPECT TO ITS PRODUCTS. The sole and exclusive remedy of Purchaser for any claim concerning this product, including but not limited to, claims alleging breach of warranty, negligence, strict liability or otherwise, is the replacement of product or refund of the purchase price, at the sole option of BASF. Any claims concerning this product must be received in writing within one (1) year from the date of shipment and any claims not presented within that period are waived by Purchaser. BASF WILL NOT BE RESPONSIBLE FOR ANY SPECIAL, INCIDENTAL, CONSEQUENTIAL (INCLUDING LOST PROFITS) OR PUNITIVE DAMAGES OF ANY KIND.

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BASF Corporation
Construction Systems

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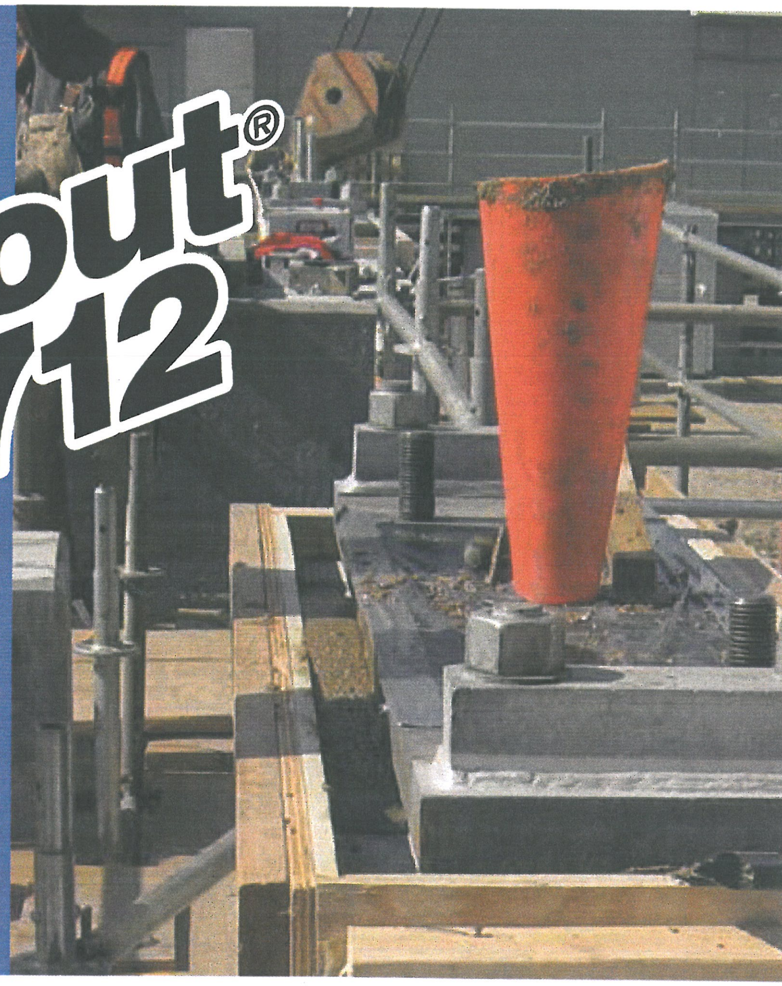
Customer Service 1(800) 433.9517
Technical Service 1(800) 243.6739

Version: July 1, 2013

MAPEI®

Planigrout® 712



High-Performance, Nonshrink, DOT Grout

CORROSION™ INHIBITOR ENHANCED

DESCRIPTION

Planigrout 712 is a one-component, nonshrink, nonmetallic, cement-based DOT (Department of Transportation) grout that meets CRD C621 and ASTM C1107 standards. *Planigrout 712* contains a corrosion inhibitor and silica fume, as well as a special blend of fine aggregate and plasticizers that provide exceptional placing and performance characteristics.

FEATURES AND BENEFITS

- Excellent compressive strength and positive expansion for structural grouting applications
- Provides superior resistance to water penetration, freeze/thaw cycles and de-icing salts
- One-component system that requires only the addition of potable water
- Has extremely low chloride content and is free of metallic aggregates, aluminum powder and gypsum

INDUSTRY STANDARDS AND APPROVALS

- Conforms to ASTM C1107 and CRD C621 standards

LEED Points Contribution	LEED Points
MR Credit 5, Regional Materials*	Up to 2 points

** Using this product may help contribute to LEED certification of projects in the categories shown above. Points are awarded based on contributions of all project materials.*

WHERE TO USE

- For use as a nonshrink, premixed plastic-to-flowable-to-fluid structural grout in applications requiring full load-bearing and stabilization. Use as a structural grout for columns, machine bases, anchor bolts and base plates.
- *Planigrout 712* is also suitable for precast, cast-in-place and prestressed concrete applications.
- For interior and exterior applications over clean, properly prepared concrete substrates
- For structural grouting and anchoring in residential, commercial, industrial, institutional, marine and infrastructure applications. *Planigrout 712* achieves high compressive strengths (greater than 8,000 psi [55,2 MPa] in a flowable consistency in 28 days).

LIMITATIONS

- For depths greater than 2" (5 cm) and up to 6" (15 cm), contact MAPEI's Technical Service Department for recommendations.
- Do not use for extreme dynamic load applications, such as electric turbine generators and stamping presses, or in place of a structural epoxy grout for superior chemical resistance. Consult MAPEI's Technical Services for product recommendations.
- Do not add other additives or cements to *Planigrout 712.*
- Ensure that *Planigrout 712* is protected from freezing after placement and until final set, and that the minimum temperature is maintained at 41°F (5°C) during and 3 days after placement.

Planigrout® 712

- Ensure that *Planigrout 712* is used in confined areas and not intended for concrete restoration.
- Do not use damaged or previously opened bags.

SUITABLE SUBSTRATES

- Properly prepared, structurally sound, fully cured masonry and concrete substrates (at least 28 days old)

Consult MAPEI's Technical Services Department for installation recommendations regarding substrates and conditions not listed.

SURFACE PREPARATION

- Ensure that all substrates are clean, structurally sound, stable and solid, with all loose materials or unsound concrete removed.
- Thoroughly clean the surface of substances that could affect the bond strength of *Planigrout 712*, including dirt, paint, tar, asphalt, wax, oil, grease, latex compounds, form release agents, laitance, loose toppings, foreign substances and any other residues.
- Reference ACI 351.1R or 351.2R (see "Related Documents" chart) for surface preparation and grouting procedures.
- Thoroughly wet the concrete surface (prepare to a saturated surface-dry [SSD] condition). Remove all standing water from low areas on the foundation, as well as in bolt holes.
- Ensure that the concrete substrate and ambient room temperatures are between 41°F and 95°F (5°C and 35°C) before application. Maintain temperatures within this range for at least 72 hours after the placement of *Planigrout 712.* Water and material should be maintained at about 70°F (21°C).

MIXING

Note: Choose all appropriate safety equipment before use. Refer to the (Material) Safety Data Sheet for more information.

1. Into a clean mixing pail, pour about 3/4 of the required amount of cool, clean potable water (see "Technical Data" table for mixing ratios). The water demand will vary depending on temperature, humidity, mixing equipment and material. Use the minimum amount of water required to achieve the desired consistency.
2. Slowly add *Planigrout 712* to water while mixing, using a low-speed mixer. Do not hand-mix *Planigrout 712.* Add as much of the remaining 1/4 of water as needed to achieve the desired consistency. Mix for up to 3 minutes, scraping down any unmixed powder after 1 to 2 minutes. Remix to a smooth, homogenous consistency.
3. Place immediately after mixing.
4. Do not overwater material, or it will not perform as specified.

PRODUCT APPLICATION

Read all application instructions thoroughly before installation. Reference ACI 351.1R or 351.2R (see "Related Documents" chart) for grouting procedures.

1. Plastic application: *Planigrout 712* may be rodded or chained into place.
2. Flowable application: *Planigrout 712* may be used with a low-pressure grout pump, or poured, hand-rodded and chained into place.
3. Fluid application: *Planigrout 712* meets ASTM C939 consistency requirements, which allows placement to tight clearances from 1/2" to 2" (12 mm to 5 cm).
4. *Planigrout 712* is recommended for jointing structural precast components and for filling rigid joints up to a thickness of 2" (5 cm).
5. To facilitate the filling of hard-to-reach areas, use a wood strip, steel rod or chain. Do not vibrate.
6. For anchor bolt/dowel grouting, the hole diameter should be 1" (2,5 cm) greater than the bar diameter. When anchoring, degrease any anchor bolts. Isolate *Planigrout 712* from direct contact with aluminum.
7. Because *Planigrout 712* is designed for various consistencies and such characteristics as workability and mechanical strength, conduct a preliminary test or mockup to verify installation capabilities. Consult MAPEI's Technical Services Department regarding specific project requirements.

CURING

- Curing is recommended for 72 hours after placement using wet curing, damp burlap, polyethylene sheeting or a suitable water-based curing compound.
- Protect from excessive heat and wind.
- Reference ACI 308.1 Standard Specification for Curing Concrete.

CLEANUP

Wash hands and tools promptly with water before the material hardens. Cured material must be mechanically removed.

Product Performance Properties

Laboratory Tests	Results		
***Planigrout 712* before mixing**			
Physical state	Powder		
Color	Gray		
***Planigrout 712* mixed** (based on desired product fluidity, mix with designated clean potable water)			
	Plastic	**Flowable**	**Fluid**
Mixing ratio (water per 50-lb. [22,7-kg] bag)	3.95 U.S. qts. (3,74 L)	4.23 U.S. qts. (4,0 L)	5.07 U.S. qts. (4,80 L)
Flow table typical value (ASTM C230)	100% to 125%	125% to 145%	Efflux < 30 seconds (ASTM C939)
Pot life	1 hour	1 hour	1 hour
Initial set (ASTM C191)	< 5.5 hours	< 6 hours	< 7 hours
Final set (ASTM C191)	< 7.5 hours	< 8 hours	< 9 hours
Compressive strength (ASTM C942)			
1 day	> 4,000 psi (27,6 MPa)	> 3,600 psi (24,8 MPa)	> 2,500 psi (17,2 MPa)
7 days	> 7,200 psi (49,7 MPa)	> 6,200 psi (42,8 MPa)	> 5,700 psi (39,3 MPa)
28 days	> 9,000 psi (62,1 MPa)	> 8,000 psi (55,2 MPa)	> 6,500 psi (44,8 MPa)
Flexural strength – ASTM C348 (CAN/CSA-A23.2-8C)			
28 days	> 1,400 psi (9,66 MPa)	> 1,200 psi (8,28 MPa)	> 1,000 psi (6,90 MPa)
Bond strength (ASTM C882)			
28 days		> 2,200 psi (15,2 MPa)	> 2,100 psi (14,5 MPa)
Volumetric change	Conforms to ASTM C1107 and CRD-C621 standards		
Bleeding (ASTM C940)	Unnoticeable	Unnoticeable	Unnoticeable

Protect containers from freezing in transit and storage. Provide for heated storage on site and deliver all materials at least 24 hours before work begins.

Shelf Life and Application Properties

Shelf life	1 year in original bag stored in a dry, heated, covered and well-ventilated place

CSI Division Classification

Non-Metallic, Nonshrink Grouting	03 62 13

Packaging

Product Code	Size
15850000	Bag: 50 lbs. (22,7 kg)

Approximate Coverage*

Size	Yield
Per 50-lb. (22,7-kg) mixed unit	0.43 cu. ft. (0,0122 m^3) bag at flowable consistency

** Coverage shown is for estimating purposes only. Actual jobsite coverage may vary according to substrate conditions and setting practices*

Planigrout® 712

RELATED DOCUMENTS

Grouting Between Foundations and Bases for Support of Equipment and Machinery	ACI 351.1R
Report on Foundations for Static Equipment	ACI 351.2R
Standard Specification for Curing Concrete	ACI 308.1

Refer to the (M)SDS for specific data related to VOCs, health and safety, and handling of product.

STATEMENT OF RESPONSIBILITY

Before using, user shall determine the suitability of the product for its intended use and user alone assumes all risks and liability whatsoever in connection therewith. **ANY CLAIM SHALL BE DEEMED WAIVED UNLESS MADE IN WRITING TO US WITHIN FIFTEEN (15) DAYS FROM DATE IT WAS, OR REASONABLY SHOULD HAVE BEEN, DISCOVERED.**

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Edition Date: June 20, 2013
PR: 5338 MKT: 6809

APPENDIX G.

CONSTRUCTION FIELD TRIP REPORT

Three construction site visits were arranged to evaluate field construction procedure and strength variation in grout cube specimens. The first two visits took place at the Chicken Creek project site on 12 July, 2017 and at the Slana River project site on 17 July of 2017. At the Slana River, three sets of twelve 2 in. × 2 in. cube specimens (total of 36 samples) were made for compressive strength test in laboratories at UAF and DOT&PF Nothern Region Materials Lab. At the Chicken Creek, a total of 33 cube specimens were cast. After being stored at the site more than 24 hours after casting, the specimens were transported to Fairbanks. Specimens were cured in either a lime bath or a curing cabinet maintained at 73 °F and 95-100% relative humidity. Compressive strength test results of cube specimens did not indicate a significant variation that exceeds the requirement in ASTM C1107 although some variation was present between the 3 sets made by different persons.

The third trip was arranged for a site visit at the bridge construction on Sterling Highway between mileposts 58 and 79 to evaluate the field construction procedure and strength variation of grout cube samples collected from site on July 20th 2018.

G.1 Chicken Creek Project Site

Figure G-1 shows the location of the Chicken Creek project site. The bridge is a single span bridge that contains four DBT girders. Figure G-2 shows the longitudinal keyways of the bridge as they were grouted. At the site, grout was mixed in an Imer Mortarman 750 Series Mixer for 5 to 10 minutes at 35 rpm as specified in the user manual of the mixer. The mixer can be seen at the top, right corner of the figure.

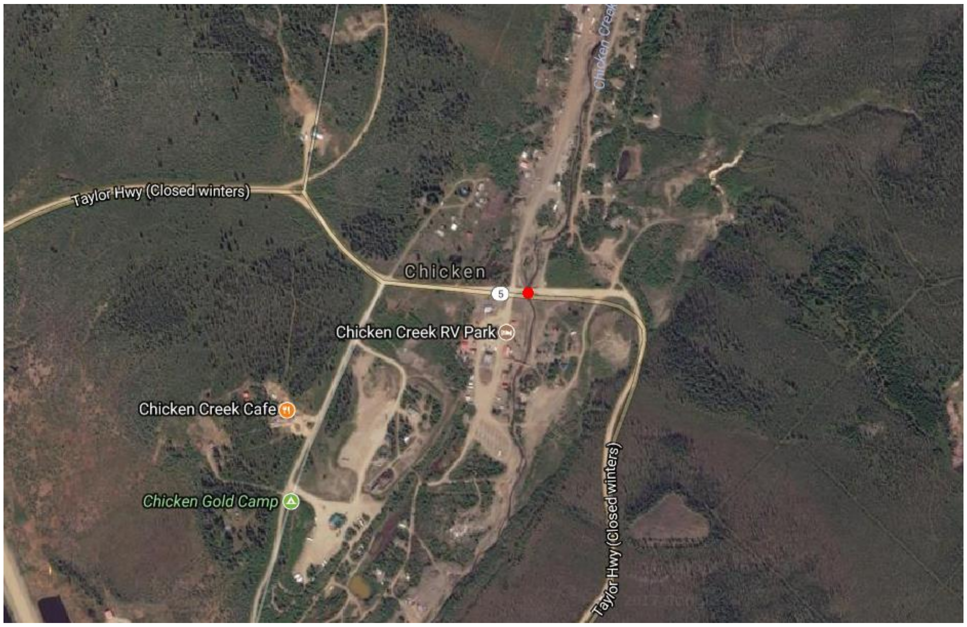


Figure G-1. Site location for Chicken creek project (google maps)

Figure G-2. Longitudinal keyways of the bridge

The grout was Dayton Superior Sure-Grip High Performance Grout. The manufacturer's specifications can be found in Appendix F. The surface preparation, grout mixing, and grout placing followed those specifications. The surface was cleaned and wetted before grouting. The required saturation time is 24 hours, however concrete was saturated for 11 hours prior to grout placement at the site. The keyway surface was at surface saturated dry condition when grout was placed. The backer rod was placed below the joint.

Among three types of mix in the specifications, fluid mix was used. This mix requires the most amount of water. For a 50 pound pre-packaged bag of grout, 4 quarts of water was added. Mix was poured through a wooden form, and the surface was flattened using a trowel as shown in Figure G-3. On the finished grout surface, Dayton Superior Cure and Seal 309 J18 was sprayed to build a liquid membrane that prevents moisture evaporation as shown in Figure G-4. Grout was cured for 3 days.

From the 6th and last batch of grout, 2 in. × 2 in. cube specimens were molded by DOT&PF Material Lab technician, DOT&PF field technician, and UAF researcher. After molding, the specimens were wrapped with wet burlap and stored in coolers. The coolers were placed under the bridge for at least 24 hours before transporting to Fairbanks. At DOT&PF Northern Region Material Lab and UAF laboratory, specimens were demolded and stored in a saturated lime bath. Also a moisture cabinet in Figure G-5 was used to store some specimens at UAF.

(a) Grout pouring form (b) Surface finishing with a trowel

Figure G-3. Grouting operation in Chicken Creek project site

(a) Spray cure container (b) Liquid membrane

Figure G-4. Liquid membrane used in Chicken Creek project site

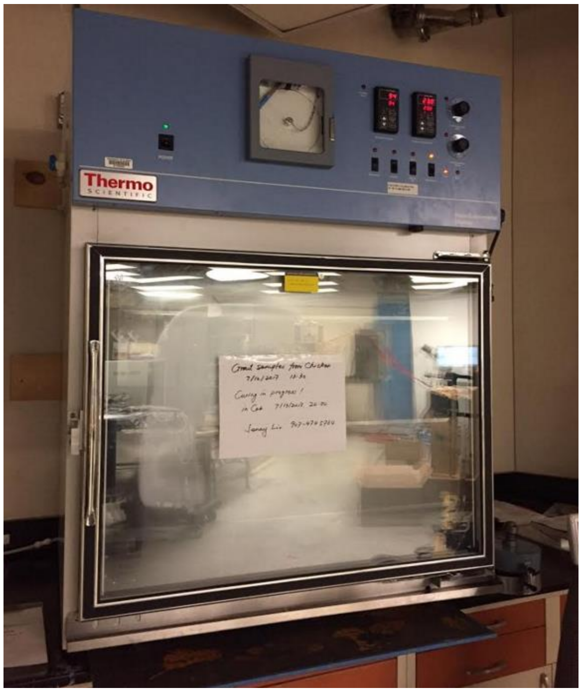


Figure G-5. Concrete curing moisture cabinet in UAF

The compressive strength of specimens were tested at 1, 3, 7, and 28 days. Specimens made by DOT&PF Material Lab technician and UAF researcher were tested at the UAF lab. Specimens made by DOT&PF field technician were tested at the DOT&PF Northern Region Material Lab. Two laboratories have different test machines as shown in Figure G-6.

(a) DOT&PF Northern Region Material Lab

(b) UAF Lab

Figure G-6. Concrete/Grout compressive strength test machines

Table G-1 shows the compressive strength test results of specimens. There was no case where the variability requirement in ASTM C109 was not satisfied. In two cases, two specimens were used instead of three since the variability limit for three specimens was not satisfied. The 28-day compressive strength was much greater than 9000 psi for all specimens.

For 1-day test of specimens made by DOT&PF Northern Region Material Lab technician, the average of three specimens was 7371 psi. The 8.7% variability limit for three specimens became 641 psi. The maximum variation among specimens was 791 psi, which is larger than the variability limit. Therefore, two results were selected and its variability was compared with 7.6% of the average of the two, 7628 psi. The variability limit is 580 psi, and the variation between the two specimens is 40 psi. So the average of two specimens was used in the table.

For 3-day test of specimens made by DOT&PF field technician, the average of three specimens was 8714 psi with a variation of 901 psi. The variability limit for three specimens was 758 psi (8.7% of average). Since the variation was larger than the limit, two specimens were selected. The average of two specimens was 8473 psi with a variation of 356 psi. The variability limit, 7.6% of the average, was 644 psi. Therefore, the average between the two specimens satisfied the variability requirement.

Table G-1. Compressive strength test results of grout from Chicken Creek project

	Specimen #	Compressive Strength, f_c' (psi)			
		1-day	3-day	7-day	28-day
DOT&PF Northern Region Material Lab (UAF Test; Moisture Cabinet)	1	7648	8996	9969	10743
	2	6857	9525	9956	11115
	3	7608	9216	9471	10574
	Average	7628 [a]	9246	9799	10811
	8.7%	641	804	853	941
DOT&PF Field Technician (DOT Test; Lime Water)	1	NA	9197	8904	10951
	2	NA	8295	8988	11349
	3	NA	8651	8631	11093
	Average		8473 [a]	8841	11131
	8.7%		758	769	968
UAF Research Team (UAF Test; Lime Water)	1	7670	9993	10773	12565
	2	7904	10208	10618	12319
	3	8176	10590	10443	12164
	Average	7917	10263	10611	12349
	8.7%	689	893	923	1074

NOTE: a. the average was calculated from two specimens since the variation among 3 specimens was 791 psi so two data were used with 7.6% limit.

Figure G-7 shows the average compressive strength with curing time. All specimens tested at 28 days were well over 9000 psi specified by DOT&PF and the variation was within the limit in ASTM C109.

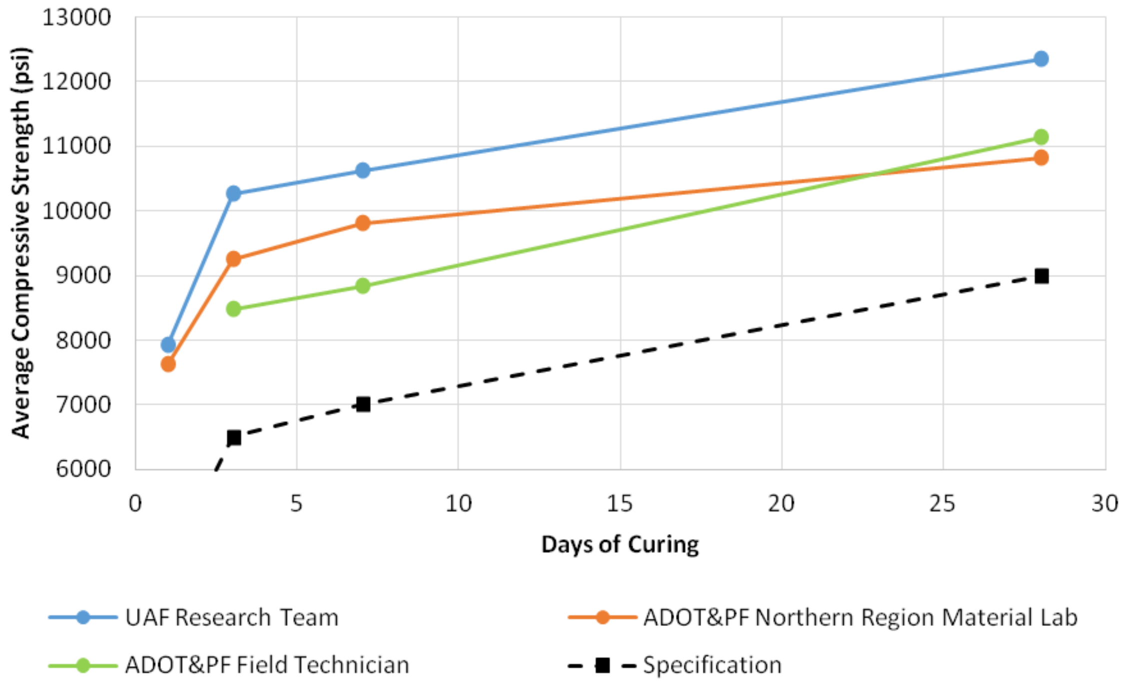


Figure G-7. Average compressive strength of grout from Chicken Creek

G.2 Slana River Project Site

Figure G-8 shows the location of the Slana River project site. The bridge is a two-span bridge that contains six DBT girders in each span. The grout used for this project was the same as the Chicken Creek project, Dayton Superior Sure-Grip High Performance Grout. This project was larger in scale, as there are two spans and each span required about 20 batches of grout for 5 keyway joints. Each batch was made by mixing 10 bags of grout with 10 gallons of water.

The contractor for grouting job was the same one as at the Chicken Creek project. Surface cleaning at this project was the same as was done at the Chicken Creek project, however the surface saturation time was only 4 to 5 hours instead of the required 24 hours prior to grout placement. The keyway surface was at surface saturated dry condition at time of placement. The backer rod was placed, although the gap is wider than the backer rod in some places. Spray foam was used to contain the gap. Figure G-9 shows keyways between girders before grouting.

The mixer used in this project was the same one used at the Chicken Creek project, however the seal in the mixer was broken and water leaked. Mixing time was 5 minutes. Application of each batch to the keyway was within 30 minutes. A wooden form was used for grout pouring and the surface was finished with a cement trowel. Grout pouring was done in two layers, and it took more than 30 minutes to pour the second layer on the top of the first. Temperature of the grout was 72.4 °F at the time of pouring. Temperature at the joint and girder were 66 °F and 62 °F, respectively. Water was sprayed on finished grout surface and the finished surface was covered with wet burlap and plastic sheet to cure for 3 days.

Specimens collected by DOT personnel and UAF research team were taken from the 3rd or 4th batch. 2 in. cube molds were wrapped in wet burlap and stored in coolers at the site for more than 24 hours before being transported to Fairbanks.

Figure G-8. Site location for Slana River project (google maps)


Figure G-9. Longitudinal keyways of bridge

Table G-2 shows the compressive strength test results of specimens. All cases satisfy the variability requirement in ASTM C109 with three or two specimens. In one case, two specimens were used instead of three since the variability limit for three specimens was not satisfied. The 28-day compressive strength was greater than 9000 psi for all specimens.

For 28-day test of specimens made by DOT&PF field technician, the average of three specimens was 10936 psi. The 8.7% variability limit for three specimens became 951.4 psi. The maximum variation among specimens was 1057 psi, which was larger than the variability limit. Therefore, two specimens were selected and its variability was compared with 7.6% of the average of the two, 10631.5 psi. The variability limit was 808 psi, and the variation between the two specimens was 287 psi. So the average of two specimens was used in the table.

Table G-2. Compressive strength test results of grout from Slana River project

	Specimen #	Compressive Strength, f_c' (psi)			
		1-day	3-day	7-day	28-day
DOT&PF Northern Region Material Lab (DOT Test; Lime Water)	1	7676	7455	8620	9657
	2	7573	7560	8960	9686
	3	7448	7876	8467	9731
	Average	7565	7630	8682	9691
	8.7%	658.2	664	755	843
DOT&PF Field Technician (UAF Test; Moisture Cabinet)	1	8054	8646	8689	11545
	2	7868	8475	8570	10488
	3	7908	8620	8704	10775
	Average	7943	8580	8654	10632[a]
	8.7%	691	747	753	1057
UAF Research Team (UAF Test; Lime Water)	1	7073	7954	7995	9220
	2	7149	7411	8506	9206
	3	6704	7441	7940	9335
	Average	6975	7602	8147	9254
	8.7%	607	661	709	805

NOTE: a. the average was calculated from two specimens since the variation among 3 specimens was 1058 psi so two data were used with 7.6% limit.

Figure G-10 shows the average compressive strength with curing time. Again, all specimens tested at 28 days were over 9000 psi specified by DOT&PF and all sets were within acceptable variability prescribed in ASTM C109.

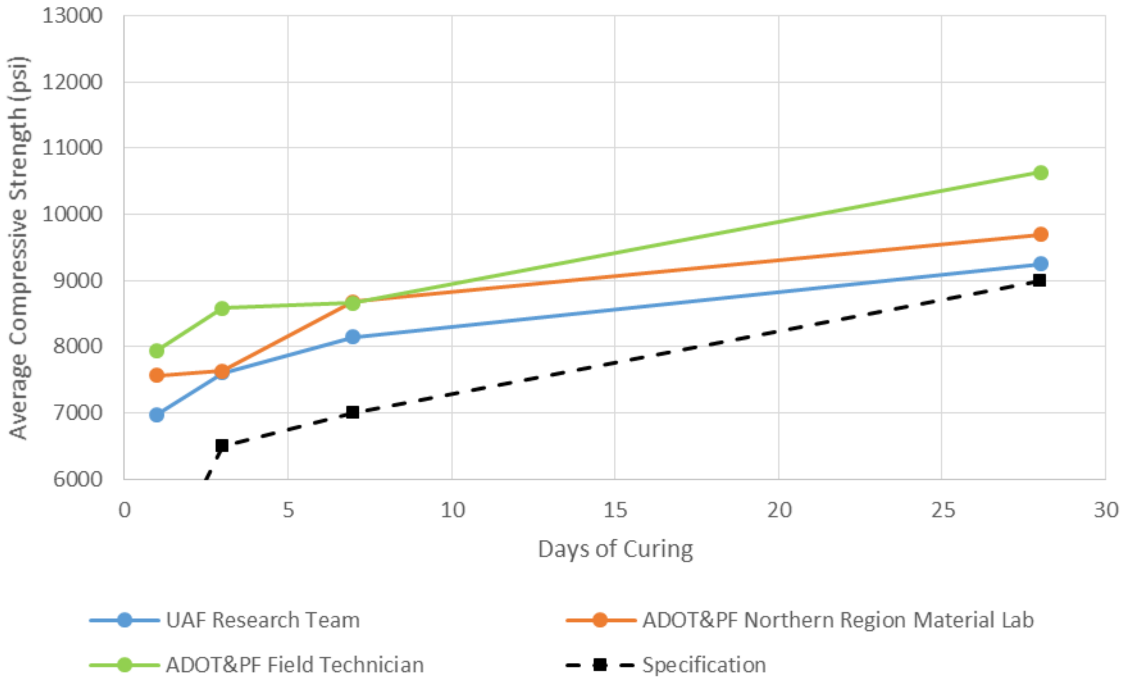


Figure G-10. Average compressive strength of grout from Slana River

G.3 Bridge on the Sterling Highway

The bridge construction site is located near milepost 71 on the Sterling Highway as shown in Figure G-11. On July 20th 2018 the weather conditions were mostly sunny at 24°C at the time of grouting. The material used in this project is Sakrete Precision Nonshrink Construction Grout 50 lb. bag (shown in Figure G-12) with 3/8" pea gravel mixed in. 2 keyways had been filled on the 19th, and the remaining 4 were filled on the 20th of July.

Before grouting, the keyways were not pre-wet, even though 24 hours soak is usual as shown in Figure G-12. Other preparation was performed in accordance with the manufacturer's requirements. The backer rod was placed securely below the joint, and appeared to have uniform spacing along the length.

The grout bags were palletized and covered in plastic, resting atop the concrete girders for storage until the time of grouting as shown in Figure G-13. The mixer used in this project was a Whiteman 7 cubic foot mixer in Figure G-14 that was used for the first time in this project. The mixing time is 5 minutes, but rotation speed is not specified by the manufacturer, instead the default rotation speed for the mixer was used. The consistency of grout mix was plastic (1 gallon of water for 1-50lb. bag of grout). But, 3/8" pea gravel was added to extend the grout, which make the water content greater than the one in the manufacturer's specification. So, the grout was made by mixing 4 – 50 lb. bags of grout and 1 – 60lb. bag of 3/8" gravel with 18 quarts of water. Grout was then poured into a wheelbarrow, and the shoveled into the keyways. The surface was then covered in wet burlap and then a plastic sheet to retain moisture as shown in Figure G-15.

Figure G-11. Site location for Sterling Highway project (google maps)

Figure G-12. Empty keyway just before grouting

Figure G-13. Product used for Sterling Highway project (Sakrete Precision Nonshrink Grout)

Figure G-14. Whiteman 7 cubic foot mixer used on site for grout mixing

Figure G-15. Grout curing with wet burlap and plastic cover

Twelve 2″×2″ cube specimens were made from the first grout batch on the 20th of July, at about 3:00PM, according to ASTM C1019, using 4 sets of 2″ cube molds. Ambient and grout temperature during sampling were about 24°C and 23°C, respectively. After casting cube specimens, cube molds were wrapped in wet cloth and plastic bags, then placed into a cooler and stored next to the southernmost bridge girder to keep away from the afternoon sun. After 24 hours the specimens were demolded and transported to UAF. Each cube was wrapped with wet cloth and placed in a zip-lock bag as shown in Figure G-16. Bags of specimens were stored in a cooler during the trip from the site to the UAF lab. Specimens were then cured in a moisture cabinet and tested at UAF.

Table G-3 shows the strength test results of specimens. In the table, the average compressive strength and a variation limit of 8.7% of average are evaluated. The maximum variation of test results is smaller than the variation limit for each test day.

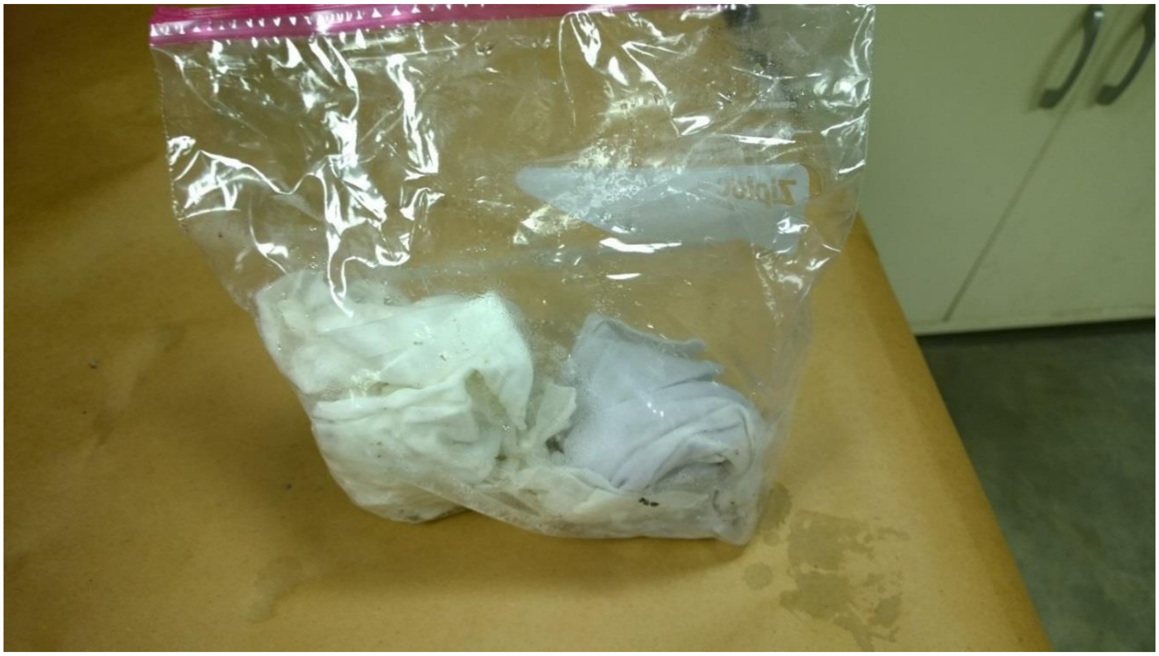


Figure G-16. Cubes transported to the UAF lab

Table G-3. Strength Test Results (Sakrete Precision Non-Shrink Construction Grout)

Specimen Number	Day Test	Peak Load (lb)	Compressive Strength (psi)	Average Strength (psi)	Maximum Variation (psi)
1	3	27405	6851		
2	3	27620	6905	6734 (8.7%: 586)	459
3	3	25785	6446		
4	7	29945	7486		
5	7	31240	7810	7585 (8.7%: 660)	350
6	7	29840	7460		
7	28	38820	9705		
8	28	41295	10324		
9	28	39630	9908	9947 (8.7%: 865)	619
10	28	38885	9721		
11	28	39405	9851		
12	28	40690	10173		

In Table G-4 and Figure G-17, average strength from the test are compared with the strength values specified by the manufacturer. The measured 7-day and 28-day strengths are about 1000psi greater than values in the manufacturer specification. Test results from the previous site visit are also compared in the table and the figure. A different grout material, Dayton Superior Sure-Grip grout, was used in the Slana River project, and cube specifications were made on 7/17/2017. The 28-day strength of both materials, Sakrete and Sure-Grip, was specified as 9000psi, and they reached more than 9000psi in the test results. It should be noted that Sure-Grip was mixed in fluid consistency and Sakrete was mixed in plastic consistency.

Table G-4. Average Strength of Grout Materials from Site Visits (unit: psi)

Days Cured	Slana River Project (Dayton Superior Sure Grip Grout)		Sterling Highway project (Sakrete Precision Non-Shrink Construction Grout)	
	Test Results	Specification	Test Results	Specification
1	6975	4500	NA	3000
3	7602	6500	6734	NA
7	8147	7000	7585	6500
28	9254	9000	9947	9000

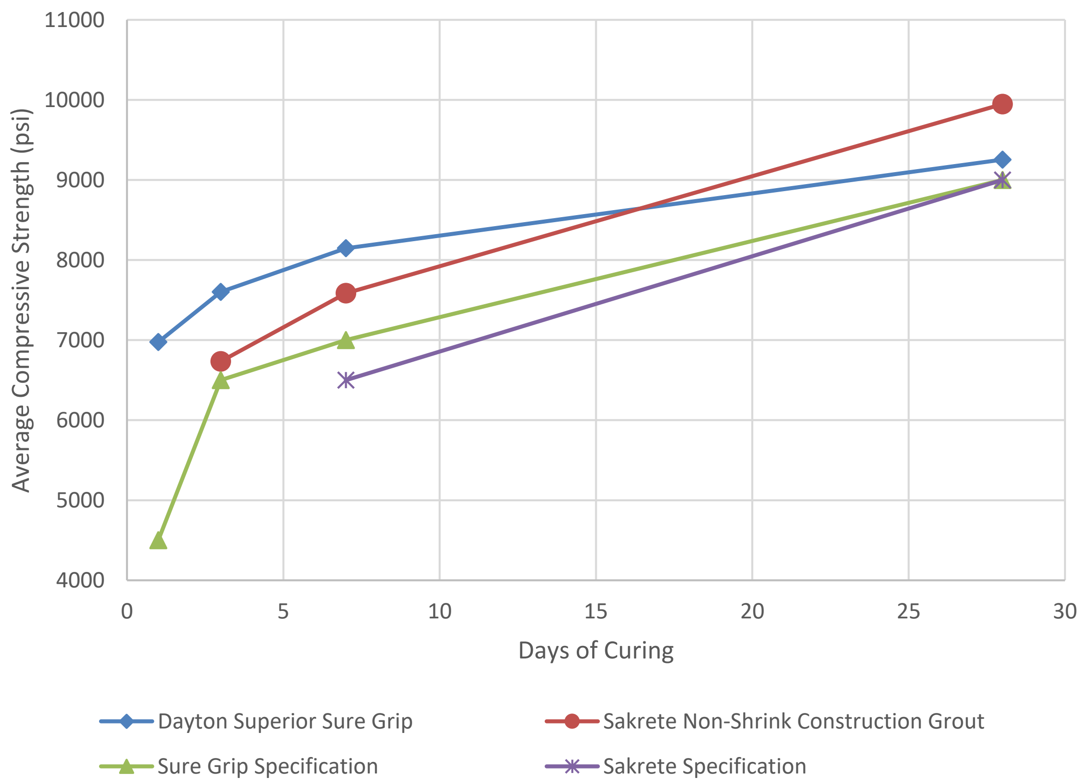


Figure G-17. Comparison between Sakrete specimens (Sterling Highway) and Sure Grip specimens (Slana River)

G.4 Summary

11 sets of 3 cube specimens were used in the compressive strength test for the Chicken Creek project, and 12 sets of 3 cube specimens were tested for the Slana River project. Specimens were made by UAF researcher, DOT&PF Northern Region Material Lab technician, and DOT&PF field technician using the same grout mix provided by the contractor. All specimens were stored and transported together. There were no test results that violated the variability requirement in ASTM C1107. Also 28-day strength reached more than 9000 psi.

Despite having reported identical mix proportions and mixing equipment, the specimens from Chicken Creek generally had a higher average compressive strength at 3, 7, and 28 days than the specimens from the Slana River project site. It was noticed that grout mix used to cast specimens in the Slana River project was more watery than the one in the Chicken Creek project. Although the same material was used and the same initial curing and transportation methods were applied, there were differences in strength among specimens made by different persons. However, the significance of workmanship factor was not clear since other factors such as machines used for the test and curing method can interactively influence the test results. The factors and their influence on compressive strength test results will be studied in the further tasks.

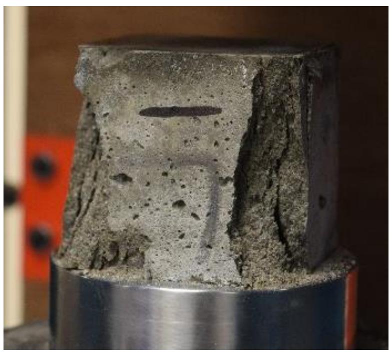
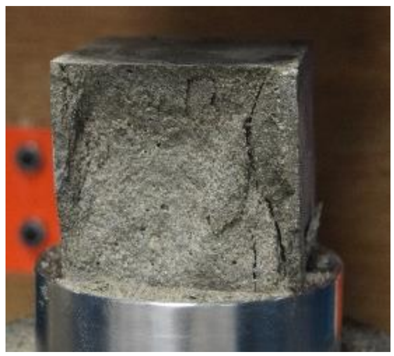
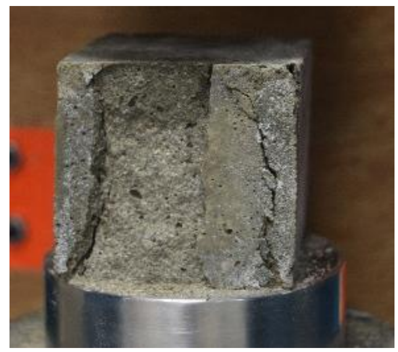
G.5 Photos of Specimens during Compressive Strength Test

G.5.1 Chicken Creek Site

1-Day Test (7/13/2017)
Photos are not available.

3-Day Test (7/15/2017)

NR-Lab Technician

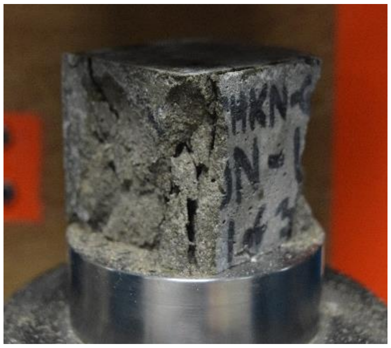




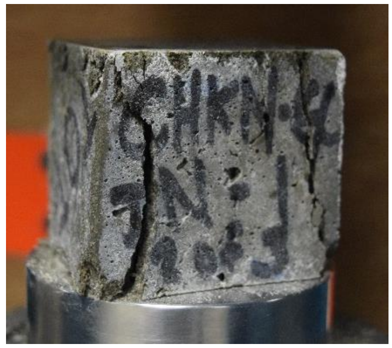
UAF

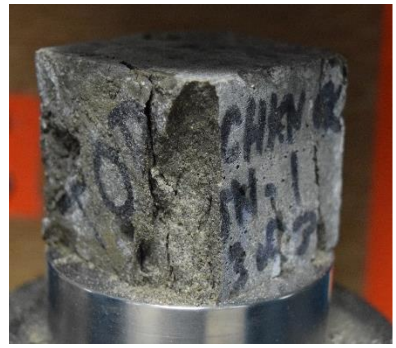
Field Technician

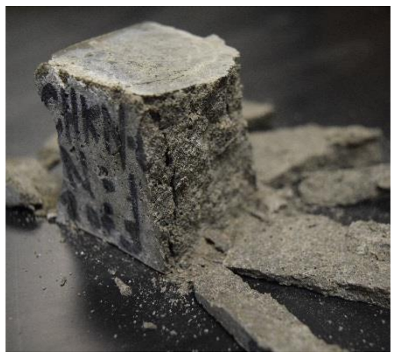

7-Day Test (7/19/2017)

NR-Lab Technician

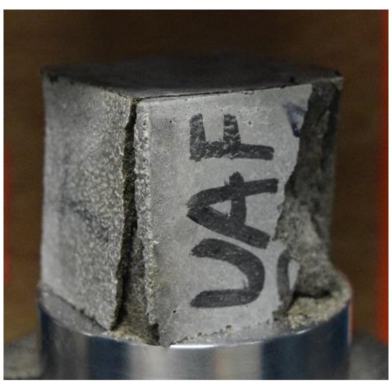


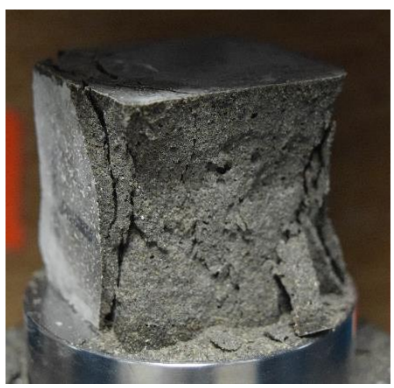


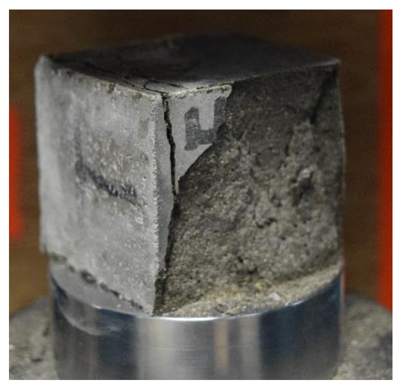




UAF





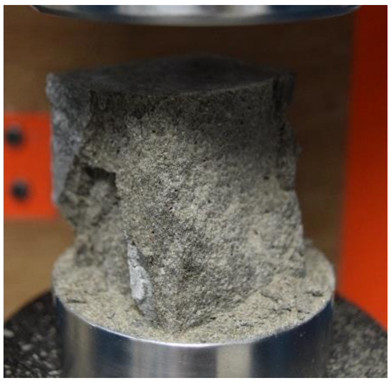
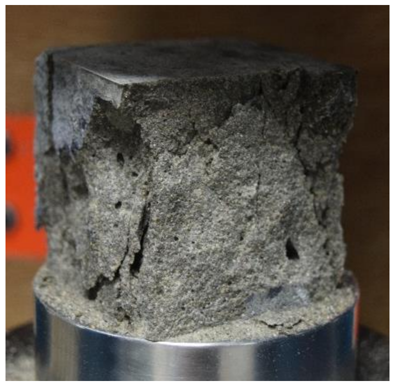
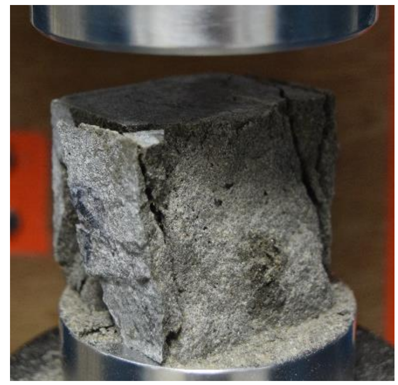


Field Technician

Photos are not available.

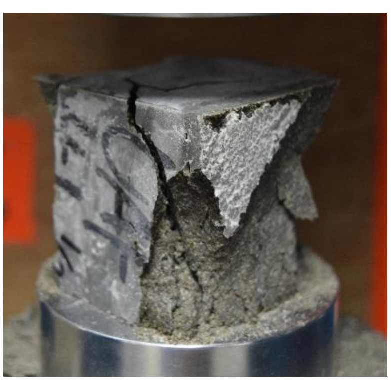
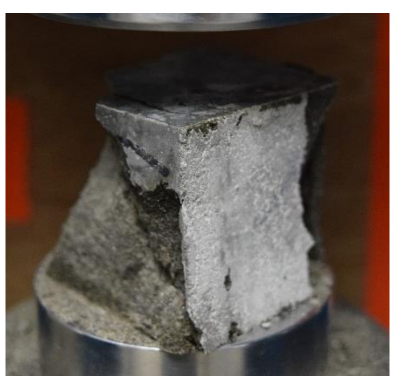
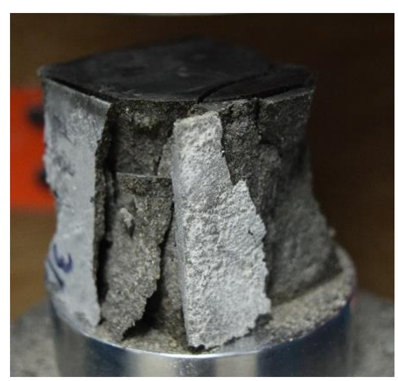
28-Day Test (8/9/2017)

NR-Lab Technician



UAF



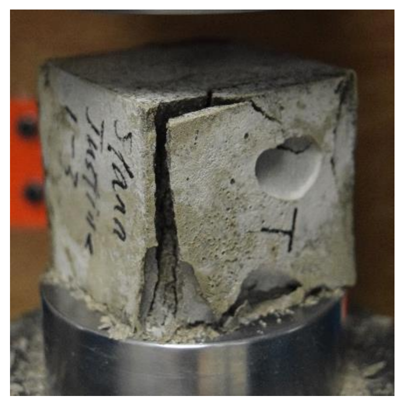
Field Technician

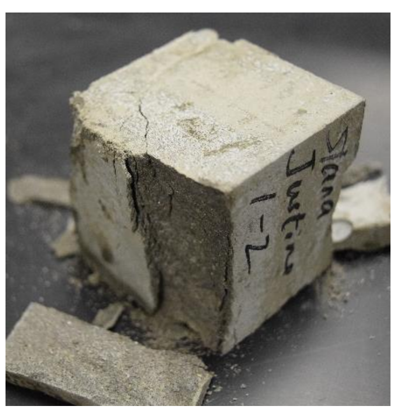
Photos are not available.

G.5.2 Slana River Site

1-Day Test (7/18/2017)

NR-Lab Technician



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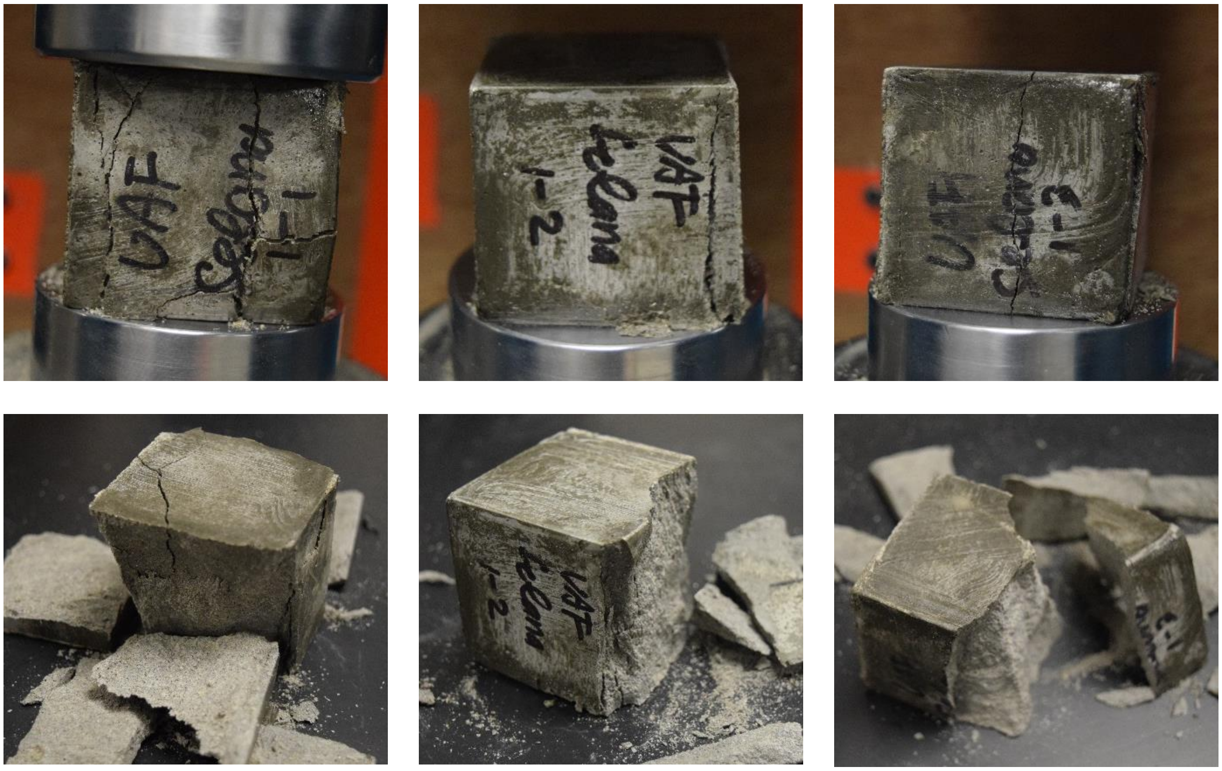
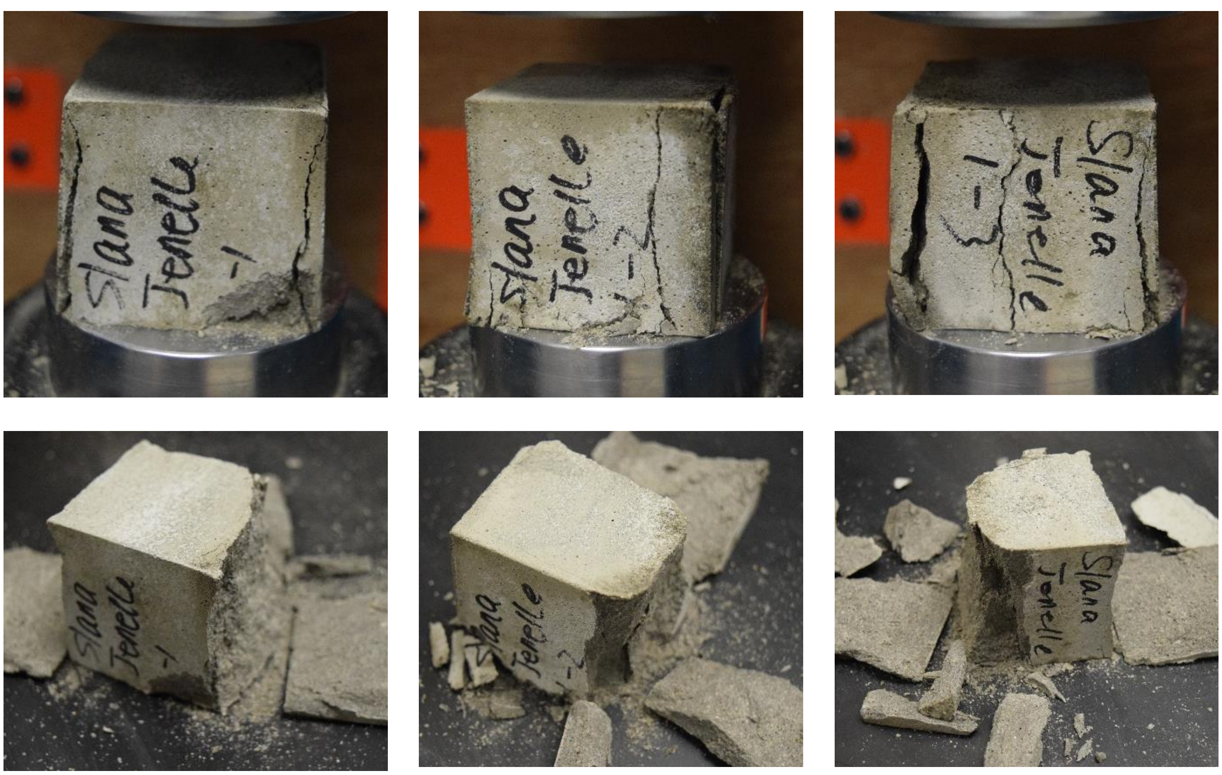


Field Technician

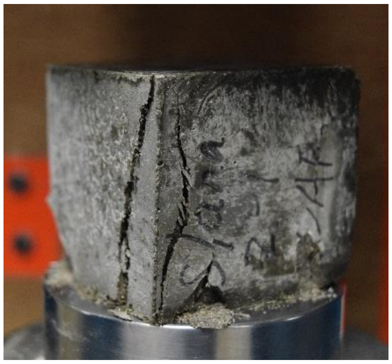


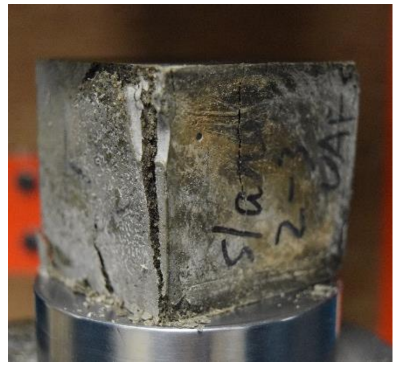
3-Day Test (7/20/2017)

NR-Lab Technician

Photos are not available.

UAF





Field Technician

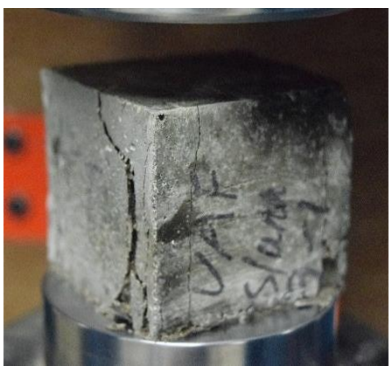
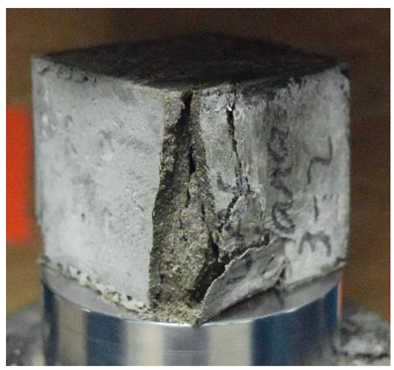
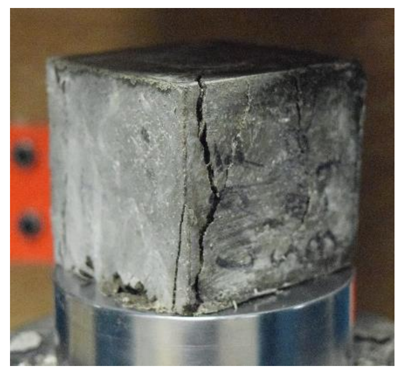


7-Day Test (7/24/2017)

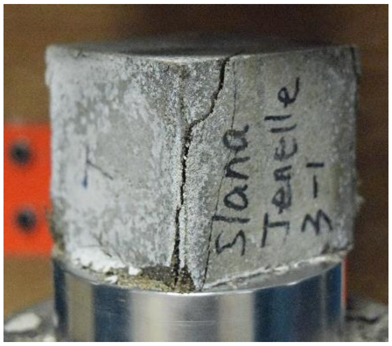
NR-Lab Technician

Photos are not available.

UAF


Field Technician

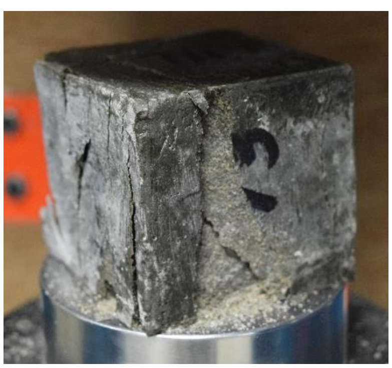


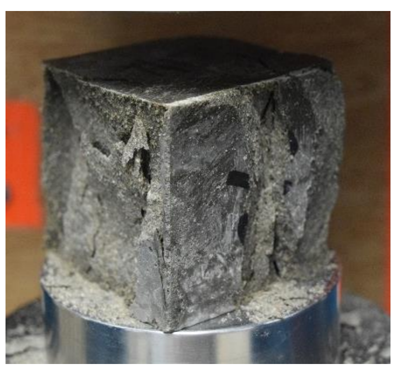
28-Day Test (8/14/2017)

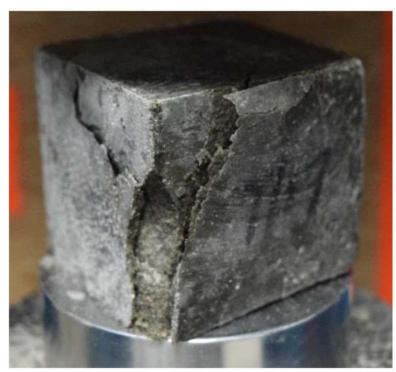
NR-Lab Technician

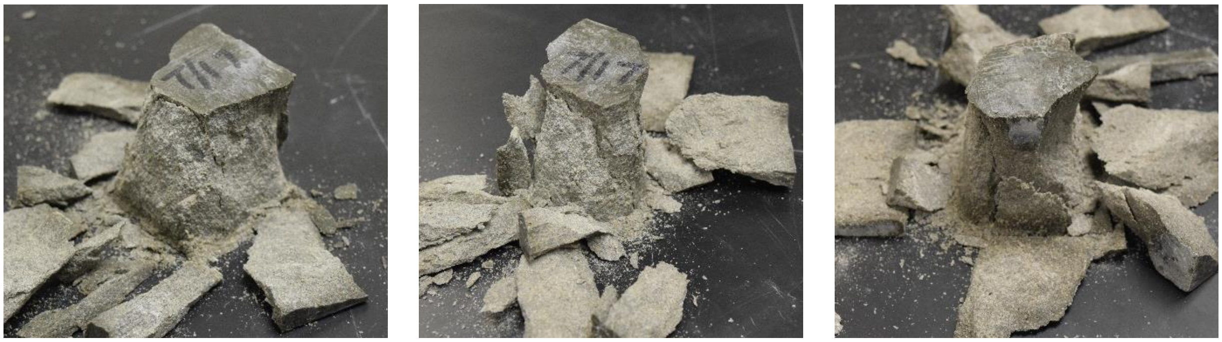
Photos are not available.

UAF

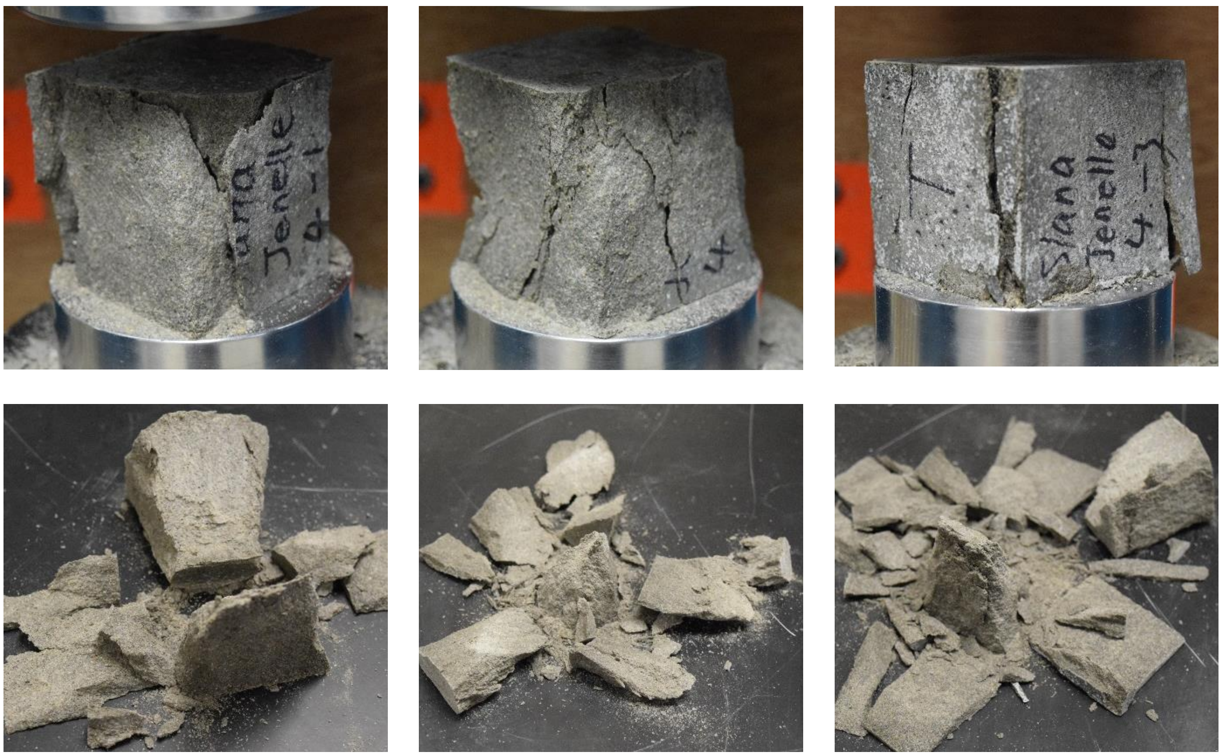








Field Technician



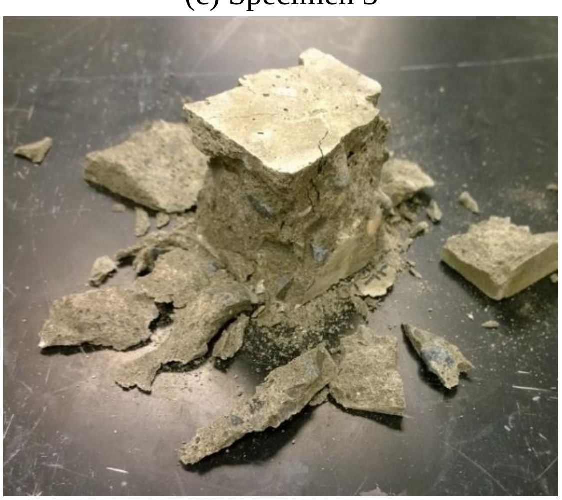
G.5.3 Bridge on the Sterling Highway

(a) Specimen 1

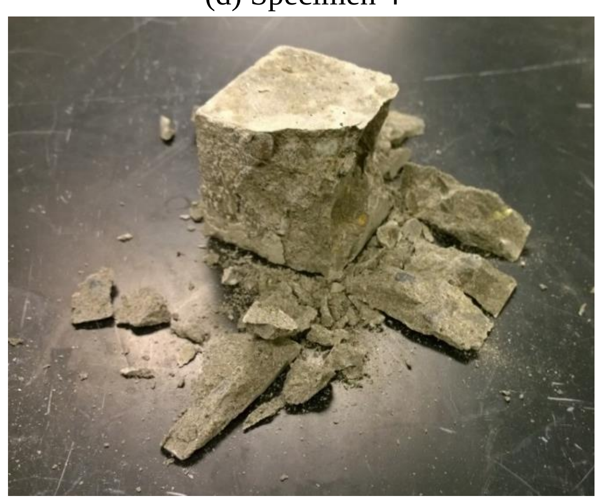
(b) Specimen 2

(c) Specimen 3

(d) Specimen 4



(e) Specimen 5



(f) Specimen 6


(g) Specimen 7


(h) Specimen 8


(i) Specimen 9


(j) Specimen 10


(k) Specimen 11


(l) Specimen 12